ENVIRONMENTAL EFFECTS OF COPPER MINE TAILINGS RECLAMATION WITH BIOSOLIDS - FIELD AND LABORATORY EXPERIMENTS

by

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A THESIS SUBMITTED IN PARTIAL FULFILMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

in

THE FACULTY OF GRADUATE STUDIES

DEPARTMENT OF BIO-RESOURCE ENGINEERING

We accept this thesis as conforming

to the required standard

THE UNIVERSITY OF BRITISH COLUMBIA

April 1995

Department of Bio-Resource Engineering

The University of British Columbia
Vancouver, Canada

Date April 28, 1995

ABSTRACT

Anaerobically digested biosolids (treated sewage sludge) were applied to copper mine tailings (pH 8.0) in Princeton, B.C. to determine how well biosolids could achieve land reclamation on a site prone to wind erosion in a semi-arid climate (350 mm mean annual precipitation). In October 1992, biosolids at 62, 77 (two plots), and 179 dry tonnes/ha (dt/ha) were applied to 0.5 ha plots. In the first growing season, vegetation established on all plots without irrigation, and the 77 dt/ha treatment led to the best vegetation quality and yield (5500 kg/ha). Trends in the first growing season included: lower foliar Mo concentrations, higher foliar Cu:Mo ratios, decreased soil pH, and increased concentrations of TKN, NH_4-N, NO_3-N, Total P, Bray P-1, Total Fe, and Total Hg with increasing application rates. Nitrate in the tailings below 60 cm was negligible. Metal concentrations were below the CCME criteria (1991) for agricultural and residential soils except for Cu.

Associated with the field trial were laboratory leaching experiments consisting of two runs of 26 columns and one run of 10 pots testing application rates of 0, 30, 100, and 300 dt/ha biosolids. Leaching experiments primarily estimated the magnitude of nitrate leaching, the mineralization rate of biosolids, and the behaviour of metals. The first column run was conducted under wetter conditions than the other trials. Under wetter conditions, the leaching of nitrate, TKN, and TP was minimal. Under dryer conditions, TKN leaching was below 0.6 kg/ha for all columns except col. H (103 kg/ha), and nitrate leaching was less than 0.4 kg/ha for all columns except col. G (123 kg/ha) and col. H (79 kg/ha). The high nitrate concentrations were probably due to a preferential flow. Mineralization rates ranged from 17 to 31% for the wetter run (10 weeks) and from 29 to 43% for the dryer run (13 weeks). Mineralization was highest for 30 dt/ha treatments. For the 300 dt/ha treatments, soil mineral N ranged from 200 to 745 kg/ha under wetter conditions and from 1200 to 3000 kg N/ha under dryer conditions. Nitrogen losses increased with application rate (30-34% of added N was lost for 300 dt/ha biosolids). Metal concentrations were below the CCME criterion for residential use except for Cu.

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ACKNOWLEDGEMENT

The successful completion of this thesis could not have been realized without the cooperation of numerous people. I would like to thank my committee members for being approachable and helpful in the various stages of this project. My special thanks goes out to Dr. Sie-Tan Chieng for his continued lessons, assistance, advice, and encouragement throughout my studies, and to Dr. Art A. Bomke for his advice and critical reviews, especially in the last stage of the thesis preparation. I would also like to thank the Greater Vancouver Regional District, especially Craig C. Peddie, for their willingness to accept research proposals from students, for their financial support, and for getting me involved with the Princeton Demonstration Projects. For their contributions to particular project phases I would like to thank Micheal D. Van Ham (U.B.C. Forestry, proposal preparation), Donna Salahub (GVRD, project engineer), Dr. Lawrence E. Lowe (U.B.C. Soil Science, soil chemistry), Dr. Ping Liao and Adeline Low and Yuncai Gao (U.B.C. BIOE, laboratory methods and interpretation of results), Peter Zadorozny (GVRD, laboratory methods), J. Pehlke and Neil Jackson (U.B.C. BIOE, column setup), Tom Smith and Arlene Daniels (GVRD, field work), Dr. Antal Kozak (U.B.C. Forestry, statistical analysis), and Katherine Prairie (U.B.C. BIOE and U.B.C. Budget & Planning, statistical analysis). I would like to dedicate this thesis to my parents, Jan and Lotte Renken, as a token of appreciation for their life-long support and encouragement of self-directed work. Finally, I would like to thank my husband Steve for his patience and proofreading.

1.0 INTRODUCTION

The revegetation of mine spoils can only be achieved with difficulty. The major difficulty in mine reclamation lies in the establishment of a nitrogen mineralization cycle. Mine tailings are generally low in organic matter which contributes to the soil characteristics of low nitrogen content, low moisture retention, low infiltration rate, and high bulk density all of which hamper plant establishment and growth (Hall and Vigerust, 1983). Low nitrogen content and low organic matter are correlated since the majority of nitrogen in soils is in organic form (Salisbury and Ross, 1992).

Conventional mine reclamation techniques involve regrading of tailings where appropriate which may be followed by deep cultivation and/or spreading of overburden before the application of inorganic fertilizer and a mixture of grass and legume seeds. Mulch may also be added to the soil surface to add moisture holding capacity and to provide wind protection. Common practice in B.C. has been to fertilize and seed tailings directly without overburden or mulch, but with repeated fertilizer applications. Stroo and Jencks (1982) found mine spoils reclaimed with fertilizer, seed, and mulch were initially productive, but that little nitrogen (N) tended to remain in the soil which made repeated refertilization and reseeding necessary to achieve plant establishment. Studies have shown that periodic maintenance fertilizations seem to be necessary until the ecosystem has accumulated at least 1000 kg N/ha (Hall and Vigerust, 1983).

Another mine reclamation technique uses biosolids (municipal sewage sludge) instead of inorganic fertilizer to facilitate plant establishment and growth. The organic matter in biosolids contains nutrients, especially N and phosphorus (P), and microorganisms and their metabolites. Biosolids have the ability to complex metals and nutrients and are a longer term source of nutrients than inorganic fertilizers as most N in biosolids is in organic form and is not available for plant use until it is mineralized. Microbial processes like mineralization and biosynthesis are particularly enhanced in the rhizosphere after biosolids application and both improve mineral nutrition and enhance plant growth (Tomati et al., 1984). Biosolids can act as a mulch as well. Sopper (1993) summarized over 75 research projects that investigated the effects of biosolids utilization in mine spoil reclamation and found that a self-sustaining ecosystem can be established quickly.

This thesis evaluates the Princeton Tailings Reclamation Project, in which anaerobically digested biosolids produced at the Annacis Island Wastewater Treatment Plant (Delta, B.C.) were applied to Granby tailings (copper mine tailings) in Princeton. The environmental effects of biosolids addition on vegetation quality and yield, soil fertility, nitrate (NO_3-N) leaching, and total metal concentrations in soil were studied in the field on a demonstration project scale, and NO_3-N leaching, mineralization of organic N, and metal movement were investigated on a laboratory scale at the University of B.C. The laboratory work was conducted under more controlled conditions than the field trial and was done to complement field results. The field project was conducted by the Greater Vancouver Regional District - Residuals Management Group under permit AR-11578 issued by the B.C. Ministry of Environment, Lands, and Parks (B.C. MOE, 1992). The author conducted the laboratory project and evaluated both the laboratory and field projects statistically. Results of the field project were also reported in project progress reports prepared by the GVRD Residuals Management Group for the B.C. Ministry of Environment (GVRD, 1992, 1993b, 1994a, 1994b).

The demonstration sites are approximately 5 km southeast of Princeton, B.C., and are located on District Lot 3030-OS Plan 11297, Lot 1 (Lat. 49°27'30" N and Long. 120°29'0" W) at elevation 667 m above sea level. The demonstration plots are sloped less than 0.3% and are 17 m above native till.

Princeton is located in a semi-arid climatic zone with a mean annual precipitation of 350 mm, a mean annual temperature of 5°C (-41°C to 38°C), and 104 frost free days . The earliest last frost on record (144 years) was measured on May 22, and the latest last frost was measured on July 5. The main tailings ponds consist of loose silts and clays (Si, SiC, SiL, and SiCL) with a soil pH around 8.0 (alkaline).

The Princeton mine tailings (also called Allenby tailings or Granby tailings) originate from the nearby Allenby mill which processed copper ores originating from the Copper Mountain mine. Both the mine and mill were operated by Granby Consolidated Mining, Smelting and Power Company Ltd. which was active intermittently between 1919 and 1957. Total production from Copper Mountain was 39,774,902 tonnes of ore which produced approximately 1,043,000 tonnes of concentrate that averaged 33% copper. About 33,732,000 tonnes of tailings were produced, the majority of which were deposited in the Allenby tailings pond (McDonald and Lane, 1979). Today, this tailings pond is owned by the Town of Princeton. Approximately 4,999,902 tonnes of waste rocks were produced in the mining process.

At the Annacis Island Wastewater Treatment Plant, the process that turns raw sewage influent into anaerobically digested biosolids includes the primary treatment of influent, gravity thickening, and transfer of the thickened fraction to an mesophilic anaerobic digester. The digester is operated in continuous mode and material digests between 14 and 17 days at 38°C. After the biosolids have been digested, they are mechanically dewatered by centrifugation.

In the field trial, primarily stored dewatered biosolids were applied whereas in the laboratory trials, freshly dewatered biosolids were applied. Stored dewatered biosolids contained 3.4% total N of which 42% was in the form of ammonium (NH_4-N) at the time of application, and freshly dewatered biosolids contained approximately 3.7% N of which 11% was in the form of NH_4-N.

Although it would have been ideal to use the same methods and the same equipment for the analysis of samples collected in the Princeton Demonstration Project and the leaching experiments, this was not feasible. Instead, collected samples were analyzed in one of three laboratories: the Bio-Resource Engineering Laboratory (BIOE Lab), the Greater Vancouver Regional District Laboratory (GVRD Lab), and Norwest Soil Research Inc. (Norwest Lab). Unfortunately, the standard methods or equipment were not always the same in the three laboratories and thus, detailed laboratory methods used in the project are listed in Appendix O by parameter and laboratory to avoid confusion.

2.0 LITERATURE REVIEW

The application of biosolids to mine spoils is extremely attractive because of the benefit to both the municipality through biosolids disposal and to the environment through land reclamation. In addition, the use of biosolids for land reclamation is expected to reduce the combined costs for land reclamation and disposal of biosolids.

The main components of biosolids for reclamation use are organic matter and N. Organic matter in biosolids has been shown to improve soil physical properties by improving granulation, increasing water holding capacity, increasing soil surface temperature, and decreasing bulk density. Furthermore, organic matter in biosolids improves soil chemical properties by increasing the soil cation exchange capacity (CEC), buffering soil pH, and increasing the concentration of soluble nutrient salts (U.S. EPA, 1983).

Problems in utilizing biosolids in land reclamation may result from the oversupply of N and occasionally P and from metals, pathogens, or organic compounds that they might contain. The application of excess biosolids might cause NO_3-N addition to groundwater, luxury consumption of N by plants, loss of nutrient cations from soil, metal accumulation in soil, and metal accumulation in plants. A literature review of N behaviour in soil and metals in soil and vegetation after biosolids application follows in sections 2.1.1, 2.2, and 2.3.

Anaerobically digested biosolids are not microbiologically sterile. Typical bacterial levels in the biosolids used in this project are listed in Table 1. Possible methods of disease transmission from land applied biosolids include all forms of water and air movement and the consumption of products grown in soils to which biosolids have been applied. This project did not study the microbial effects of biosolids application to land, but a brief literature review on this subject is included in section 2.4.

TABLE 1. BACTERIA LEVELS IN BIOSOLIDS (GVRD, 1993a)

Biosolids Type	Fecal Coliform (MPN/g)	Enterococci (MPN/g)	Fecal Streptococci (MPN/g)	Salmonella (# /g)
Annacis freshly dewatered	3.0 E+5 (17)	2.0 E+5 (6)	8.6 E+3 (6)	6 (5)
Annacis stored dewatered	28 (13)	-	664 (7)	0 (6)

Notes:
All results are geometric means. The number of samples are in parentheses.
MPN/g Most Probable Number per gram of dry solids.
/g Number of bacteria per gram in dry solids.

2.1 Nutrients

The elements required by plants that will ensure good growth have been divided into macronutrients and micronutrients. Macronutrients are required in greater quantities than micronutrients. Macronutrients for plants are N, P, potassium, calcium, magnesium, and sulfur whereas boron, iron, manganese, copper, zinc, molybdenum, cobalt (not essential for all vascular plants), and chlorine are plant micronutrients (Foth, 1984).

2.1.1 Nitrogen

Nitrogen is the soil nutrient that most commonly limits plant growth and since the major portion of N in soils is in organic forms (Salisbury and Ross, 1992), soils low in organic matter will also be deficient in N. Nitrogen in biosolids occurs in ammoniacal and organic form and whilst NH_4^+ (in the liquid fraction) is immediately available for crop uptake, organic N requires mineralization first.

Nitrogen biochemistry in soils consists of the constant turnover of N during organic reactions like mineralization (organic N -> NH_4^+), nitrification (NH_4^+ -> NO_3^-), denitrification (NO_3^- -> N_2), mineral uptake (NH_4^+ or NO_3^- absorption by plants), immobilization (NH_4^+ or NO_3^- incorporation into biomass), and N_2 fixation (atmospheric N_2 fixation into biomass). In dry and high pH conditions, the mineralized NH_4^+ may also volatilize as NH_3. All but the volatilization and absorption of NH_4-N in acid soils require microbial catalysis.

Nitrogen losses from the soil result from crop removal (NH_4^+ & NO_3^-), leaching (NO_3^-), denitrification (N_2), volatilization (NH_4^+), and soil erosion (all N forms). After the establishment of a vegetative cover, N losses due to crop removal usually outweigh other N losses. A simplified diagram of the N cycle is included in Figure 1. The different stages of the N cycle are discussed in the following sections.

Typically in the early spring, a portion of the mineralized or nitrified N from biosolids is available to volatilize, leach, or denitrify due to a higher amount of mineral N available than is taken up by vegetation and due to excess water from spring melt or spring rains that can leach excess NO_3-N to lower soil layers. However, as mineralization, nitrification, and the growth of seedlings are temperature dependent, NO_3-N leaching losses are typically small when nutrients are added in the form of organic matter.

In the late fall there may be another period of NO_3-N leaching which depends on soil temperatures and organic matter available for decomposition. Nitrate may be leached or denitrified if sufficient rain is received before the soil freezes. If there is no freeze-up, the potential for leaching may persist throughout the winter although mineralization will normally cease.

In most agricultural or grassland soils, the carbon:nitrogen (C:N) ratio of soil organic matter is about 10:1 (w/w) (McGill et al., 1980). When this ratio is changed by N fertilization, addition of organic

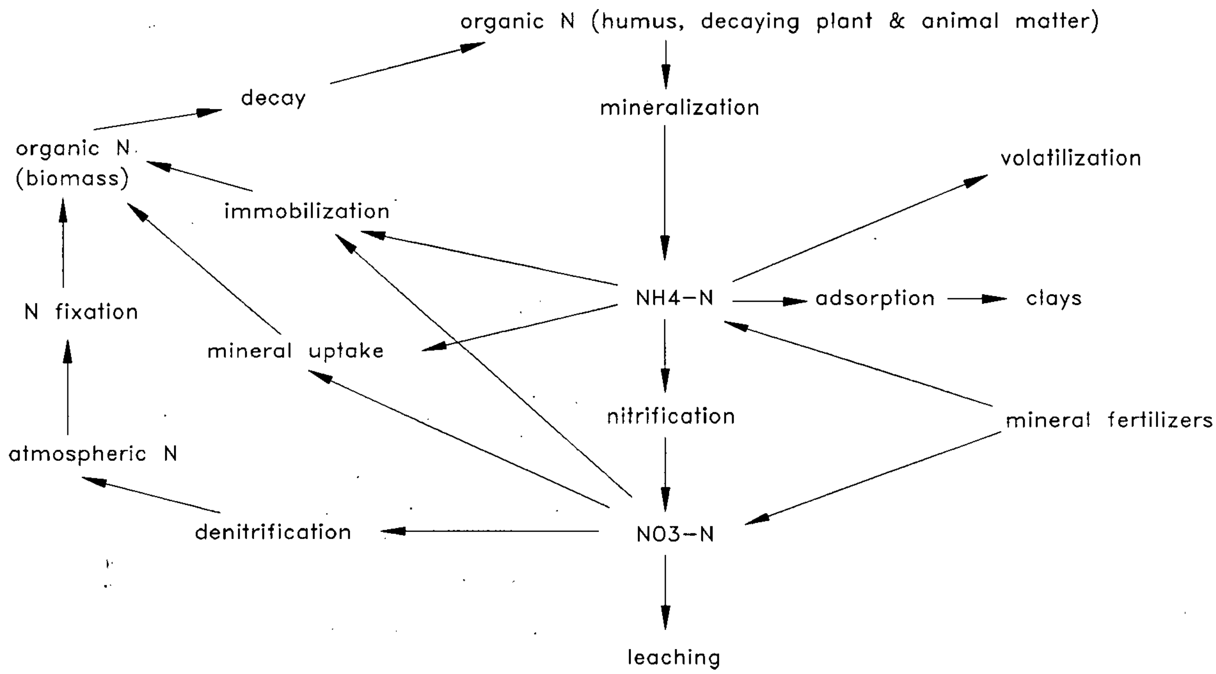

FIGURE 1. SIMPLIFIED NITROGEN CYCLE

matter, or plant uptake, soil microorganisms restore the balance by carbon oxidation, N fixation, or denitrification (Bohn et al., 1985). In the biosolids used in this project, the concentration of N ranged between 3.3 and 3.8% and the concentration of carbon ranged between 30 and 40%, thus the C:N ratio was about 10:1.

2.1.1.1 Mineralization and Immobilization of N

Mineralization is the conversion of organic N to NH_4^+ which is accomplished through aminization and ammonification (Tisdale et al., 1993). Aminization describes the breakdown of proteins into amino acids, amines, urea and CO_2 by heterotrophic bacteria and fungi. Ammonification is the breakdown of amino acids and amines and the release of NH_4^+ performed by aerobic or anaerobic bacteria, fungi, or actinomycetes (Tisdale et al., 1993). The resulting NH_4^+ ions are only stable under strongly reducing conditions (Bohn et. al. 1985).

As organic N in biosolids primarily consists of amino acids, hexoamines, and amides (U.S. EPA, 1983) ammonification is the primary process in the mineralization of organic N in biosolids.

The mineralization rate of N in soils depends on the C:N ratio, the concentration of heterotrophic bacteria, the stability of organic matter, the availability of water, the pH and Eh, and the soil temperature. Typically, the mineralization rate doubles with every temperature increase of 10°C between 5°C and 35°C. The optimum temperature for mineralization is between 30°C and 35°C. Generally, conditions favourable for nitrification also favour ammonification.

Disagreement exists among researchers concerning the effect of the rate of biosolids addition on the percent of added organic N mineralized (Sopper, 1993; Williams et al., 1984). Sopper (1993) summarized a few studies that demonstrate the varying rate of N mineralization in soils amended with biosolids. For example, Voos and Sabey (1987) added biosolids at rates of 0, 40, 80, 120 dry tonnes per hectare (dt/ha) which added 0, 1630, 3260, and 4890 kg/ha N respectively to coal mine spoil samples. The mixtures were incubated for 16 weeks in a laboratory. By the end of the experiment, NH_4-N had increased significantly with increasing application rate of biosolids, but only small amounts of NO_3-N had accumulated. A similar finding was reported by Terry et al. (1981). Terry et al. (1981) used biosolids application rates of 11.2, 22.4, and 44.8 dt/ha and found that the percent of added organic N mineralized was significantly greater at higher rates than at lower rates of biosolids addition. However, Epstein et al. (1978) and Magdoff and Cromec (1977) observed no effect on the percent of organic N mineralized at rates ranging from about 20 to 80 dt/ha, and Sabey et al. (1977) observed that the percent of organic N mineralized decreased as the amount of N added increased. Based on varying results for similar experiments that were reviewed by Williams et al. (1984), they suggested that so far unidentified factors play a role in the mineralization of biosolids after incorporation into soil.

Immobilization is the conversion of inorganic N to organic N. If decomposing organic matter in soil has a high C:N ratio (as in wood chips), microorganisms will use available N in the soil to multiply and to decompose organic matter making mineral N unavailable for plant use. After low N residues have been decomposed, decomposing microbial activity subsides and immobilized N can be mineralized back to NH_4^+ (Tisdale et al., 1993).

Approximate C/N (w/w) ratios for mineralization and immobilization are (Tisdale et al., 1993):

	C/N	%N
Mineralization	< 20	> 2
Immobilization	> 30	< 1-1.5.

2.1.1.2 Nitrification

Nitrification is the conversion of NH_4^+ to NO_3^- in a two step process accomplished primarily by aerobic chemo-autotrophs. The formation of nitrite ($NH_4^+ \rightarrow NO_2^-$) in the first step is carried out primarily by *Nitrosomonas spp.* and the formation of nitrate ($NO_2^- \rightarrow NO_3^-$) in the second step is performed by

Nitrobactor spp. In most well-drained soils the reaction rate is faster for the second step than the first step. Nitrification is acidifiying (Tisdale et al., 1993).

Nitrification Reaction (Metcalf and Eddy, 1991):
Step 1:
$55\ NH_4^+ + 76\ O_2 + 109\ HCO_3^- \rightarrow C_5H_7O_2N + 54\ NO_2^- + 57\ H_2O + 104\ H_2CO_3$

Step 2:
$400\ NO_2^- + NH_4^+ + 4\ H_2CO_3 + HCO_3^- + 195\ O_2 \rightarrow C_5H_7O_2N + 3H_2O + 400\ NO_3^-$

Nitrification is affected by the supply of NH_4^+, the population of nitrifying bacteria, the pH and Eh, and the soil temperature and moisture. However, soils differ in their ability to nitrify NH_4^+ even under similar conditions (Tisdale et al., 1993) which is likely due to the susceptibility of nitrifying bacteria to a wide variety of inhibitors. A variety of organic and inorganic agents can inhibit the growth and action of nitrifying bacteria. High concentrations of ammonia and nitrous acid can be inhibitory (Metcalf and Eddy, 1991). The optimal pH for nitrification ranges from 7.5 to 8.6, but systems acclimated to lower pH conditions have successfully nitrified (down to 4.5). A dissolved oxygen (DO) concentration in the soil solution above 1 mg/L is essential for nitrification to occur. If DO levels drop below this value, oxygen becomes the limiting nutrient and nitrification slows or ceases (Metcalf and Eddy, 1991). Generally, nitrification appears to proceed most rapidly at moisture tensions between 1/3 and 1 bar when water occupies about 80 to 90% of soil pores (Tisdale et al., 1993). As the soil moisture declines, the nitrification rate declines as well. The quantification of the effect of temperature has been difficult (Metcalf and Eddy, 1991), but the optimum soil temperature for nitrification is believed to between 25°C and 30°C although nitrification can occur over a wide temperature range (Tisdale et al., 1993).

Nitrate is only stable under strongly oxidizing conditions. The NO_3^- anion is very soluble in water and is only non-specifically adsorbed by soil colloids (Tisdale et al., 1993; Bohn et al., 1985). Therefore, excess NO_3-N tends to leach along the water potential gradient (mass flow).

In a comparative study of the reclamation of an acid strip mine spoil in Pennsylvania, Seaker and Sopper (1988) studied the difference between nitrifying populations in 5 sites amended with biosolids and a site amended with fertilizer. The biosolids-amended sites were studied 1 to 5 years following application and the fertilizer site was studied 5 years after application. They found that *Nitrosomonas* populations were not significantly different on the five biosolids-amended sites, but were two to four magnitudes greater than on the fertilizer-amended site. The *Nitrobacter* population was not only significantly larger on the most recently biosolids-amended site than on the older biosolids-amended sites, but was also four to six orders of magnitude greater than on the control site. After 5 years following application, the bacterial populations for the biosolids and the fertilizer amended sites were $7*10^4$ g^{-1} and 30 g^{-1} for the *Nitrosomonas* and $5.5*10^5$ g^{-1} and 18 g^{-1} for the *Nitrobacter* respectively. In typical soils, the nitrifying population ranges from a few hundred to 10^5 g^{-1} (Stevenson, 1982). The low nitrifying population on the fertilizer-amended sites suggests a lack of organic N which corresponded with sparse growth on the site after five years.

2.1.1.3 Denitrification

Denitrification is the conversion of NO_3^- or NO_2^- to the gases N_2O or N_2. The conversion is primarily performed by facultatively anaerobic bacteria which use NO_3-N, NO_2-N, and nitrous oxide as terminal electron acceptor when the soil is anoxic.

Denitrification Reaction:

$$2HNO_3 \xrightarrow[\text{nitrate reductase (Mo,Fe)}]{+4H^+ - 2H_2O} 2HNO_2 \xrightarrow{+2H^+ - 2H_2O} 2NO \xrightarrow{+2H^+ - 2H_2O} N_2O \xrightarrow{+2H^+ - 2H_2O} N_2$$

Denitrification losses can occur after the incorporation of biosolids into soil through the creation of anoxic microsites due to high microbial activity. Furthermore, denitrification losses in fine textured soils tend to be greater than those for coarse textured soils due to their increased water holding capacity, lower permeability, and higher likelihood of anoxic conditions since the O_2 diffusion coefficient in water in 10000 times less than in air.

Denitrification is dependent on the available NO_3^- and organic carbon concentrations, the pH and Eh, the soil moisture, and the soil texture and temperature. The dependence of denitrification rate on NO_3^- N concentration has been found to be of first order at N concentrations less than 40 mg/L and of zero order at higher concentrations (Firestone, 1982).

Denitrification increases with readily available carbon, but researchers have not determined conclusively if available carbon should be measured as total organic, water-soluble, or mineralizable carbon (Elder, 1988). Carbon supplies the energy for N reduction and provides a matrix of compounds into which reduced N can be incorporated and stabilized.

Generally, denitrification rates are increased by plants because of their release of readily available C in root exudates and sloughed off root tissues (Tisdale et al., 1993).

Denitrification is relatively constant at pH 6 to 8, but tends to decrease under acidic conditions (Firestone 1982). The temperature tolerance of denitrifying bacteria tends to vary with climatic region. Firestone (1982) reported minimum temperatures for denitrification of 2.7°C to 10°C, and maximum temperatures of about 75°C.

2.1.1.4 Volatilization

Volatilization of NH_3 occurs naturally in all soils. Volatilization losses depend on the atmospheric partial pressure of NH_3, the concentration of NH_3 and NH_4^+ in the soil solution, the pH, the soil temperature, and the cation exchange capacity (CEC).

Volatilization losses are especially high in high pH soils, but losses also increase when the soil pH is temporarily raised after a storm or flooding event (Tisdale et al., 1993).

Volatilization Reaction:

NH_4^+ --------------> $NH_3 + H^+$ (pK = 9.3)

Volatilization losses in the Princeton demonstration project are believed to have been especially high due to the use of stored dewatered anaerobically digested biosolids with 30% of the TKN in the form of NH_4^+. The NH_4-N tends not to be tightly bound in the biosolids and the trucking and application operations provided an opportunity for trapped NH_4^+ to escape.

In general, volatilization increases with increasing temperature up to 45°C. In soils with high CEC, NH_4^+ may be retained in Vermiculite or Montmorillonite (Illite).

2.1.1.5 Nitrogen Fixation

Nitrogen fixation is the process by which N_2 is reduced to NH_4^+. Principal N fixers include microbes associated with roots, especially those of legumes, free-living soil bacteria, certain free-living cyanobacteria, and cyanobacteria in symbiotic associations with fungi. Nitrogen fixation is influenced by soil pH, mineral nutrient status, photosynthetic activity, climate, and legume management.

Nitrogen Fixation Reaction:

$$N_2 \xrightarrow[\text{(Mo,Fe)}]{\text{nitrogenase}} NH_4^+$$

The activities of the roots of nitrogen-fixing plants benefits the roots of surrounding plants through excretion of N from nodules or through microbial decomposition of nodules or whole plants (Ta and

Farris, 1987). In legumes, bacterial species of *Rhizobium* or *Rhizobium*-like species are generally only effective for one legume species or group of species. All rhizobia are aerobic bacteria (Salisbury and Ross, 1993).

Rhizobia species differ in their optimum range of soil pH. For alfalfa, a pH below 6 drastically reduces the activity of *Rhizobium meliloti* in its root zone. High NO_3^- concentration in the soil can reduce nitrogenase activity and N fixation. Low photosynthetic plant activity caused by reduced light intensity, moisture stress, or low temperature will also reduce N fixation (Tisdale et al., 1993).

2.1.1.6 Nitrate in Feed

In general, biosolids applications on mine land increase the total N concentration in the foliage of vegetation (Sopper, 1993). Normally, NO_3-N taken up by plants is converted to NH_4-N which is used to form amino acids and proteins. Unfavorable growing conditions, such as drought, can interfere with the N accumulation in plants and can cause an accumulation of NO_3-N, particularly in the stalk as long as the conditions stay unfavorable (Noller and Rhykerd, 1978). This effect can be amplified by an overfertilization with N which results in a higher accumulation of N in plants. Nitrate toxicity may follow if ruminants eat NO_3-N rich stalks which overwhelm their digestive system and which may lead to an accumulation of NO_2-N in their bloodstream and a diminished ability of their blood to carry oxygen.

Sopper (1993) has been unable to find any documentation of NO_3-N toxicity occurring as a results of biosolids applications to mine land in his review of more than 75 research projects. This result is likely due to the slow-release fertilizer behaviour of biosolids and their additional benefit of providing increased water-holding capacity and mulching. In contrast, most inorganic fertilizers are in an available form and do not provide any water-holding capacity or mulching which makes droughty conditions and high NO_3-N feed more likely to occur.

2.1.2 Phosphorus

About 70 to 90 percent of P in biosolids is present as inorganic compounds. Therefore, inorganic reactions of P are of greater importance in biosolids utilization than organic reactions (U.S. EPA, 1983).

Phosphorus in soils is controlled by chemical reactions. Phosphorus is retained in soils by a multistage process that involves several known mechanisms as well as unknown mechanisms. For example, phosphate ions can be retained by substitution of OH^- groups, lattice extension, precipitation, or coordination but to date, the mechanisms of organo-P retention by soils have not been fully established. In the process of OH^- substitution, phosphate ions replace singly coordinated OH-groups.

Many soils fix large quantities of P by converting readily soluble forms of P to forms less available to plants. In general, the longer P has been in the soil, the slower is the release of P. In addition, P fixation in soils is not fully reversible. Phosphate forms difficultly soluble Fe^{3+} and Al^{3+} compounds at low pH, more soluble Ca^{2+} and Mg^{2+} compounds at pH values near neutrality, difficultly soluble Ca^{2+} compounds at pH 7-8, and more soluble Ca^{2+} compounds at pH > 8 (Bohn et al., 1985). Phosphate fixation is appreciable in all but very coarse textured soils or peat soils and is particularly high in soils rich in amorphous iron and aluminum hydroxide or allophane (Bohn et al., 1985). In general, soil organic matter increases the P availability to plants.

2.2 Metals in Vegetation

Typical biosolids contain heavy metals in varying concentrations. The absorption of metals contained in biosolids by plants after the addition of biosolids to soils is complex. Factors that contribute to the complexity include metal concentrations of biosolids, soil pH, Fe and Al concentrations in the biosolids, soil concentrations of Fe, Al, Ca, P, Zn, soil organic matter content, and soil clay content. As well, the phytotoxic metal tolerance of plant species and the amount of metals accumulated by various plant species are highly variable (U.S. EPA, 1983). In general, the plant uptake of metal ions from soil is dependent on the concentration and speciation of metals in the soil solution and the translocation of metals from the roots to other plant tissues.

Plants grown on all soils appear to respond to an increased concentration of heavy metals in soils with absorption. However, plants tend to take up metals bound to organic materials slower than metals in ionic form. After biosolids application, one reason for metal uptake by plants is that increased nitrification enhances growth and acidifies the soil which facilitates plant uptake of elements like Zn, Cd, Cr, Pb, and Ni (Henry and Harrison, 1991). Because As, Pb, and Hg are not taken up readily by most plants, the metal of greatest concern is Cd. The reproductive parts of plants (flowers, fruits, seeds) usually contain lesser concentrations of Cd, and respond less rapidly to Cd additions to soils than do vegetative parts. However, the phytotoxic tolerance of plant species to Cd added to soil and the amounts accumulated by various plant species are highly variable (U.S. EPA, 1983).

CAST (1980) found that levels of Cd and Zn in plant tissues increased with increasing metal application rates irrespective of whether the metals were applied as inorganic metal salts or with biosolids, and that the Cd and Zn concentrations varied seasonally. Higher accumulations tended to occur at higher soil temperatures and/or moisture stress.

According to Corey et al. (1987) and Chaney (1990), plant uptake of trace metals from biosolids-amended soils tends to approach a maximum as the application rates increase. This phenomenon might be explained by the recent discovery of the mechanism that detoxifies metals by chelation with phytochelatins (Gekeler et al., 1989; Steffens, 1990; and Rauser, 1990). Phytochelatins seem to be produced by numerous plant species but so far they have only been identified when toxic amounts of trace elements were present in the soil solution.

Other studies indicate that a decrease in trace metal concentrations in vegetation from biosolids-amended sites may occur over time when biosolids are applied on a one-time basis. Metal concentrations in tall fescue from a Ohio mine spoils amended with up to 716 dt/ha of biosolids were considerably lower in the third than in the first growing season (Haghiri and Sutton, 1982). On anthracite refuse in Pennsylvania, Cu, Zn, and Cd increased in reed canarygrass tissues in the first growing season after biosolids application, but in the second and third growing seasons, with few exceptions, metal concentrations decreased to control levels or below (Kerr et al., 1979).

Several factors may account for decreasing metal concentrations over time. Iron and P added with biosolids may complex with metals, forming sparingly soluble precipitates. According to Ernst (1976), the absorption rate of heavy metals by plants can be reduced in the presence of high amounts of calcium and P. Metals may also bind with the humic fraction of biosolids (Haghiri and Sutton, 1982). Another reason for reduced metal concentrations in vegetation might be a dilution effect that occurs as a result of increased biomass production after biosolids application (Kerr et al., 1979).

To minimize plant uptake of metals, plants can be genetically selected for the property of low translocation of heavy metals as well as their metal tolerance.

Copper plant uptake is not fully understood, but it seems likely that although Cu is almost entirely complexed in the root environment, it dissociates prior to plant absorption. Genotypical differences in Cu absorption by plants clearly exist, for example, ryegrass extracts up to twice as much Cu from the soil as wheatgrass (Graham, 1981). Copper tolerant herbaceous plants have been identified in areas of high soil copper concentration. On British soils, the following Cu tolerant species can be found: *Festuca ovina*, *F. rubra*, *Agrostis stolonifera*, *A. tenuis*, *Deschampsia caespitosa* and the dicotyledons *Silene maritima*, *Armeria maritima*, and *Calluna vulgaris* (Woolhouse and Walker, 1981). Studies show that no arborescent species appear to have evolved a high degree of copper tolerance (Woolhouse and Walker, 1981).

2.3 Metals in Soil

Mine tailings are generally devoid of soil organic matter at the start of reclamation so that the behaviour of metals in soil is primarily dependent on the quantity and quality of soil amendments that are added and the physical and chemical characteristics of the spoil. Right after the addition of biosolids to mine tailings, the behaviour of metals in soil will be controlled by the metal absorption capacity of biosolids, the spoil pH, and the chemical characteristics of the spoil. The metal absorption capacity of biosolids depends on the organic and inorganic (e.g. Fe and Al oxides) components in the biosolids. Generally, metals in biosolids are bound to organic components as sulfides, chlorides, carbonates, hydroxides, and other compounds that are not readily soluble (Sopper, 1993).

If the reclamation effort is successful in establishing a self-sustaining ecosystem, soil organic matter will build up in the spoil and metal interactions with the soil organic matter will become more important over time. The long-term behaviour of metals that were present at the beginning of the site reclamation and that were added with the biosolids will depend more and more on the soil organic matter and soil pH.

Smith and Giller (1992) found that concentrations of total metals in biosolids-amended soils increased linearly with soil organic matter content irrespective of the rate or frequency of biosolids addition, the duration of application, or the period which had elapsed since the last treatment. Tiller and Merry (1981) found that high soil concentrations of Cu appeared to affect the microbial, earthworm, and insect populations resulting in a slow breakdown of organic matter and slow turnover of N.

In general, the concentration of metals in the soil solution is dependent on various simultaneous equilibrium reactions, including the reactions of precipitation and dissolution (decreasing pH -> increasing solubility), adsorption and desorption, and reduction and oxidation. Metal chelation plays also an important role. These reactions are all directly or indirectly related to soil pH.

Aspects of equilibrium reactions concerning metals in the soil solution were summarized well by Kiekens (1983) and a condensed version follows below. The dynamic equilibrium of metals in soil changes with metal additions, metal uptake by plants, leaching, changes in pH, changes in redox, changes in soil moisture, and mineralization of organic matter (Kiekens, 1983).

Adsorption and Desorption

In most cases, the colloidal fraction in soil is negatively charged and adsorbs and retains cations from the soil solution. The colloidal fractions consists of clay particles, amorphous oxides of Fe and Al, and organic colloids.

Laboratory experiments by Kiekens (1980) on the behaviour of Cu, Pb, Zn and Cd in soil showed that the adsorption of heavy metals was strongly reduced in the presence of 0.01 M $CaCl_2$, indicating that Ca^{2+} competes effectively with heavy metals for the adsorption sites. This competition seemed to be greater for Zn and Cd than for Cu and Pb. This laboratory result was confirmed in field studies by Davis (1983) who conducted tests on calcareous and noncalcareous soils. On calcareous soils, plant response to Cd was limited even at much elevated soil Cd concentrations. On noncalcareous soils, there was nearly a linear relationship between plant and soil concentrations.

Adsorption (Kiekens, 1980):

in 0.01 M $CaCl_2$ soil suspension:

Cu > Pb > Cd > Zn adsorption

at low metal concentrations in soil:

There seems to be a hysteresis effect in the reaction:

$Ca\text{-soil} + M^{2+} \longleftrightarrow M\text{-soil} + Ca^{2+}$

Cu > Pb > Cd > Zn

Desorption (Cottenie and Kiekens, 1972):

pH < 5: Zn^{2+}, Cd^{2+}, Mn^{2+}

pH < 3: Cu^{2+}, Pb^{2+}

Redox Potential

In oxidizing conditions:

pH:	decreasing pH => increased solubility	(Kiekens, 1983)
pH 3-7:	soluble Cd > Zn >> Cu > Pb	(Herms, 1982; Kiekens, 1980)

In reducing conditions (Herms, 1982):

Fe^{2+} and Mn^{2+} are initially more soluble and dissolution of their oxides can release occluded trace metals.

pH > 7: higher solubility of Cd, Zn, Pb, and Cu than in aerobic conditions (soluble organomineral complexes)

pH 4-6: lower solubility of Cd, Pb, Zn, and Cu than in aerobic conditions (insoluble sulfides or organomineral complexes)

Chelation and Soil Organic Matter

Soil organic matter is an important soil component originating from plant and animal residues which have been converted to the more or less stable product of humic substances consisting of humic and fulvic acids. Humic and fulvic acids have been defined according to their solubilities. Humic acids are soluble in an alkaline medium, and fulvic acids are soluble in acid and alkaline media.

Fulvic acids primarily form chelates with metal ions over a wide pH range, thus increasing the solubility and mobility of heavy metals. The stability constant of metal fulvic acid complexes increases with increasing pH and is high for the cations Cu^{2+}, Pb^{2+}, and Fe^{3+}.

The interaction and solubilities of humic acids and metals are more complicated but are strongly pH dependent. Humic acids (HA) are insoluble in acid medium (pH < 1) but dissolve gradually as pH increases.

Chelation

pH 1-6:	insoluble Cu-humic acid complexes	(Verloo, 1974)
pH > 7:	Soluble HA can be flocculated by Ca^{2+} and Mg^{2+}, and at higher pH by Fe^{3+} and Al^{3+}	(Kiekens, 1983).

All metals are either in the form of soluble humates or precipitated as hydroxides (Verloo, 1974).

2.4 Biosolids and Pathogens

Typically, densities of pathogenic bacteria are reduced but not eliminated by anaerobic digestion. Therefore, some risks to human health exist when applying these biosolids to land. However, land application reduces the bacterial density to low values in less than 30 days when applied to vegetation or the soil surface, especially where exposed to high temperatures, sunshine (UV), and desiccation. The decline is slower when biosolids are incorporated below the soil surface due to the protection from UV light and desiccation (Long, 1993). Studies have indicated that most pathogenic bacteria and viruses are removed after passing through a meter of soil or less (Edmonds, 1979). The potential hazard from surface runoff is low after one month after application (Long, 1993).

Adult wastewater borne parasites, protozoa and helminth organisms rarely survive a mesophyilic treatment process, but their cysts and eggs are hardier and often end up in biosolids. Some biosolids can arrive at the land application site with approximately the original ova concentration. Of the various helminths, *Ascaris* ova are common, have the highest densities of any helminth in typical biosolids, and survive the longest. The survival time of *Ascaris* ova is estimated to be at least 3 months for biosolids applied to grassed plots and even after 3 years approximately 50% of the *Ascaris* ova are expected to be viable on biosolids-amended tilled or fallow plots (Long, 1993). The infective dose for helminths is one egg.

The principal means of human exposure to pathogens are ingestion and inhalation, but studies conducted in the U.S.A. and Europe showed that the incidences of disease in farm inhabitants and domestic animals on farms applying biosolids did not differ significantly from control farms that did not apply biosolids while following EPA or equivalent regulations (Long, 1993).

Good application practices that prevent the transmission of pathogens to humans include changing of exposed clothes, good personal hygiene by applicators, and wearing of face masks if dust is generated in the application of biosolids. Other biosolids management practices include the restriction of public access to treatment sites and the restriction of movement of plants or soil from treatment sites for at least one month after application (Long, 1993).

2.5 Nitrate Leaching in Soil Columns

In typical column studies examining the NO_3-N leaching behaviour, NO_3-N is added to saturated, unvegetated soil columns in the form of mineral salts dissolved in distilled water (for example as KNO_3). Sometimes both NO_3^- and chloride (Cl^-) ions are added to saturated soil columns. Nitrate and Cl^- travel at approximately the same speed through soil, but Cl^- flows inertly through soil unlike NO_3^- that can undergo bacterial conversion to other N forms in the N cycle (Bowman, 1984; Verdegem et al., 1981).

In typical experiments, NO_3-N in leachate is then studied either after a one-time or after repeated additions of distilled water to the saturated soil columns. Typically, the leachate is collected either at the bottom or at the bottom and at several depths in between the top and bottom of the columns (Elder, 1988).

Leaching experiments discussed in this text were designed differently as N was added in the form of organic N and NH_4^+ which had to either mineralize or nitrify before NO_3-N leaching could be investigated. Therefore, the leaching experiments had to be designed to resolve the dilemma of adding enough water to be able to leach NO_3-N to lower soil layers but at the same time to allow nitrification of organic N in biosolids to occur and to discourage denitrifcation losses. The dilemma is that maximum water movement through soil occurs under saturated conditions and that the conversion of NH_4-N mineralized from organic N in biosolids nitrifies only under aerobic conditions which are inhibited under saturated conditions. In general, once NH_4-N has been converted to NO_3-N, NO_3-N will leach downwards with the wetting front unless it is denitrified or taken up by plants first.

In general, the permeability of soil or hydraulic conductivity in soil columns can be estimated with Darcy's Law:

If vertical flow under constant head is assumed, Darcy's Law equals (Craig, 1992):

$$k = (q*l/A*h) \qquad \textbf{Eq. 1}$$

and if vertical flow under falling head is assumed, Darcy's Law equals (Craig, 1992):

$$k = (a*l/At_1)*\ln(h_0/h_1) \qquad \textbf{Eq. 2}$$

where

k	hydraulic conductivity	[L/T]
q	volume of water collected per unit time	[L^3/T]
l	length of the soil column penetrated	[L]
A	cross sectional area of the soil column	[L^2]
h	the hydraulic head difference between the bottom of the soil and the top of the constant depth of water above the soil column	[L]
a	internal area of standpipe connected to the top of the cylinder holding the soil	[L^2]
t_1	time it takes for the water level to drop from level h_0 to h_1	[T]

3.0 METHODS AND MATERIALS - LABORATORY EXPERIMENTS

3.1 Overview of Leaching Experiments

The leaching experiments consisted of two runs of 26 soil columns and one run of 10 pots which were shorter than the soil columns. Every column run consisted of 2 times 13 columns testing tailings from two field locations. The column runs were designed to estimate the amount and/or potential for NO_3-N leaching and metal movement that might occur after the application of biosolids (municipal sewage sludge) to tailings. The pot trial was designed to compare the mineralization rate of organic N in biosolids between very short columns (15 cm deep pots) and longer soil columns testing 45, 60, and 90 cm deep tailings. In other words, the tests examined the effect of drainage conditions on the mineralization rate of organic N in biosolids. The pot trial was conducted at the same time and under the same environmental conditions as was the second column test. The biosolids application rates 0, 30, 100, and 300 dry tonnes per hectare (dt/ha) investigated.

According to the currently valid legislation for beneficial use of biosolids in British Columbia, the biosolids used were Agricultural Low Grade Sludge (B.C. MOE, 1983).

In the column runs, a tailings/biosolids mixture was added on top of previously saturated tailings. The tailings/biosolids mixture consisted of an equivalent weight of biosolids for the various application rates, and a quantity of tailings that could fill 15 cm in the columns. The soil columns were 0.64 cm X 13.97 cm (5.5" X 0.25") Plexiglas columns and of varying heights. Out the 13 columns per field locations, 5 columns were 110 cm in length, 4 columns were 85 cm in length, and 4 columns were 70 cm in length. The biosolids application rates 0, 30, 100, and 300 dt/ha were tested in all column lengths, and the 300 dt/ha application rate was duplicated in the longest columns. The pots were 14 cm in diameter and 15 cm in height (typical plastic flower pots). The characteristics of the added biosolids are given in Table 2.

TABLE 2. BIOSOLIDS CHARACTERISTICS - LABORATORY EXPERIMENTS

Element	Run 1 *		Run 2 **		B.C. Draft Guidelines for the Disposal of Domestic Sludge (1983)	
	Annacis Freshly Dewatered Biosolids (Mar. 93)		Annacis Freshly Dewatered Biosolids (Aug. 93)		Agricultural Low Grade	Retail High Grade
		C.V. (%)		C.V. (%)		
% Moisture	74	1	72	0	-	< 70
pH (1:2)	8	1	8	2	-	-
% Loss on Ignition (@ 450 $^{\circ}$C)	71	1	74	0	-	-
Total Kjeldahl N (mg/kg)	35700	3	41900	4	-	-
Nitrate & Nitrite-N (mg/kg)	2	2	3	12	-	-
Ammonium-N (mg/kg) - extracted	3730	5	4460	3	-	-
Ammonium-N (mg/kg) - distilled	3640	2	5210	3	-	-
Total Phosphorus (mg/kg)	10500	3	13900	14	-	-
Arsenic (mg/kg)	< 9	0	< 17	0	75	75
Cadmium (mg/kg)	4	5	3	4	25	5-20
Chromium (mg/kg)	60	2	58	5	-	-
Cobalt (mg/kg)	4	9	< 3	0	150	150
Copper (mg/kg)	820	2	904	2	-	-
Lead (mg/kg)	156	2	139	5	1000	500
Mercury (mg/kg)	5.4	12	5.7	11	10	5
Molybdenum (mg/kg)	7	11	8	15	20	20
Nickel (mg/kg)	28	2	24	6	200	180
Selenium (mg/kg)	7	3	5	13	14	14
Zinc (mg/kg)	621	2	671	1	2500	1850

Notes:

* The average concentrations of 5 samples.

** The average concentrations of 4 samples.

Since spring is generally considered to be the period of greatest NO_3-N leaching, the leaching experiments were designed to simulate spring runoff or spring melt and rainfall conditions.

Besides being subject to a water regime, the columns were subject to light and temperature changes. The experiments were not conducted under completely controlled conditions. The temperature and light conditions were allowed to fluctuate diurnally and from week to week.

The overall average temperature for leaching runs 1 and 2 were 17.8°C and 17.2°C respectively. In leaching run 1, the average weekly temperature increased from 15.3°C at the start to 23.4°C at the end of the run. In leaching run 2, the soil temperature decreased from 20.8°C at the start to 14.1°C at the end of the run. The temperature regime was lower than the optimal temperatures for bacterial conversion of organic N to NH_4-N and NO_3-N, but are assumed to be typical for soils. Refer to Appendix C for details.

The light conditions in the laboratory varied with the sunlight and due to a different laboratory setup. Leaching run 1 was set up in a different laboratory than leaching run 2 due to space restrictions set out by the university administration. The room which housed the first experiment was facing west and fairly bright whereas the room for the second leaching run was facing north and relatively dark. Exposure to filtered sunlight (through a window) can lead to photosynthetic algal growth. In the leaching experiments, algal growth was assumed to not have had an effect on N concentrations as algal growth is dependent on sunlight, CO_2, and minerals. Little algal growth was noticed in the first leaching run and none was noticed in the second leaching run.

3.2 Water Regime

The water additions to the leaching columns and pots were supposed to simulate spring conditions in the field. In the original design, all experiments were to be replicated four times, testing the same setup and same water regime with tailings collected from four sites in the field. In the actual leaching runs, two column runs were conducted investigating leaching behaviour for tailings from two sites at a time. The water addition, temperature, and light conditions changed between the leaching runs due to the poorer drainage behaviour of the tailings than had been anticipated, and due to the conducting of the experiment in a different laboratory and at a different time.

To determine typical spring conditions for the research site, a data analysis was conducted on 20 years of precipitation data collected at the Princeton Airport (Dec. 1, 1971 - Nov. 30, 1991). The calculations showed that the average precipitation is 350 mm per annum, 130 mm from November 1 to January 31, and 60 mm from February 1 to April 30.

An analysis of storm contributions to annual precipitation showed that 2-Day storms contributed the majority of the precipitation followed in importance by 3-Day storms. An analysis of storm contributions to seasonal precipitation showed that in the winter months (November - April) 4-Day and longer storms followed by 2-Day storms contributed the majority to the precipitation whereas in the summer months 2-Day storms followed by 4-Day storms were main contributors to the seasonal precipitation. Based on these results, 2-Day storms were simulated in the leaching experiments as early spring conditions mark the change from winter precipitation, temperature, and light conditions to summer conditions. Refer to Appendix C for a detailed overview of precipitation information.

To be able to simulate typical field conditions in the laboratory, the appropriate magnitude of 2-Day storms were estimated with a Single Set Maximum Frequency Analysis (Gumbel, 1954). All water additions were kept below the two year return period for 2-Day storms with exception of the first water addition which was supposed to simulate spring melt water on the tailings surface. The total amount of water added per leaching run was comparable to the 2-year maximum of seasonal precipitation in the 6 months period between November 1 and April 30. Refer to Appendix C for details.

In the first leaching run, a total of 180 mm distilled water was added over 10 weeks to all columns whereas in the second leaching run, a total of 163 mm distilled water was added over 13 weeks to all columns and pots. Water was added slowly through the spout of a typical watering can (garden supply). Refer to Table 3 or Appendix C for details on the water regime.

TABLE 3. WATER REGIME FOR THE LEACHING EXPERIMENTS

		Leaching Run 1		Leaching Run 2 and Pot Trial	
Week	Day in Leaching Run	Distilled water (DI) added to Columns (mm)	DI added to Columns/Week (mm)	DI added to Columns (mm)	DI added to Columns/Week (mm)
1	1	33		33	
	2	31	64	31	64
2	8	26		26	
	9	6	32	6	32
3	15	13		13	
	16	4	17	4	17
4	22	13			
	23	4	17		
5	29	13			
	30	4	17		
6	36	13			
	37	4	17		
7	43				
	44				
8	50			3	
	51			9	12
9	57	3		5	
	58	5	8	5	10
10	64	3			
	65	5	8		
11	71				
	72				
12	78			5	
	79			9	14
13	85			5	
	86			9	14
Total Water added (mm):		180		163	

In the second leaching run, water additions beyond the first three weeks were spaced out over time compared to run 1 to allow mineralization and nitrification to occur at a higher rate.

3.3 Column Design

To estimate the leaching behaviour of NO_3-N in the tailings a diameter of 5.5" (13.97 cm) was chosen to minimize edge effects while at the same time allowing easy loading and unloading of the columns. The columns were manufactured out of 0.25"X 5.5" Plexiglas tubes (0.64 cm X 13.97 cm) fitted with bottom plates with 0.6" holes (1.5 cm) in their centres. Male hose adapters (1.3 cm or 0.5") were screwed into the holes (together with plumber's tape to provide a good seal) to which 30 cm rubber hoses were connected with hose clamps. The rubber hoses were left open to the atmosphere during the leaching runs. Water draining flowed from the soil columns through the rubber hoses into 1 liter plastic receiving bottles. The column setup and the column design are shown in Figures 2 and 3, and photographs of the column setup are included in Appendix P.

The longest leaching columns were also fitted with a joint at 50 cm height to allow for easy removal of tailings at the end of the run. These joints proved to be unnecessary in the experiment as the tailings slipped out of the columns relatively easily and without the mixing of tailings in different layers. The joint sealed very tightly and the space between the two halves inside the columns was barely perceptible to the touch. The joints were kept shut throughout the experiments.

3.4 Loading and Saturation of the Soil Columns

Before tailings were loaded into the columns, all columns were filled to a height of 10 cm with medium sized rocks (1-2 cm in diameter) to ensure good drainage above the centre outlet. Then tailings were loaded at the same profile depth into the soil columns as they had been found in the field (on unvegetated sites). For example, 60-75 cm tailings from the field were loaded into the 60-75 cm layer

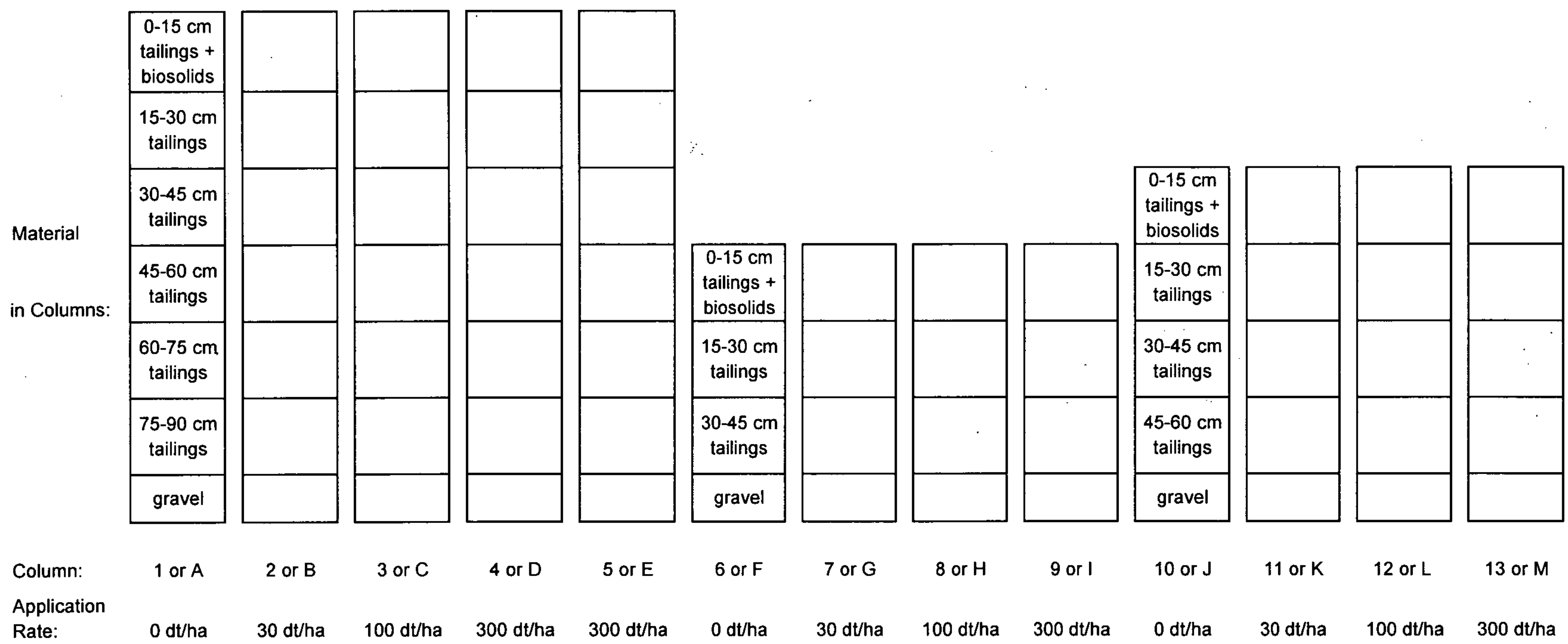

FIGURE 2. COLUMN SETUP FOR ONE LEACHING RUN

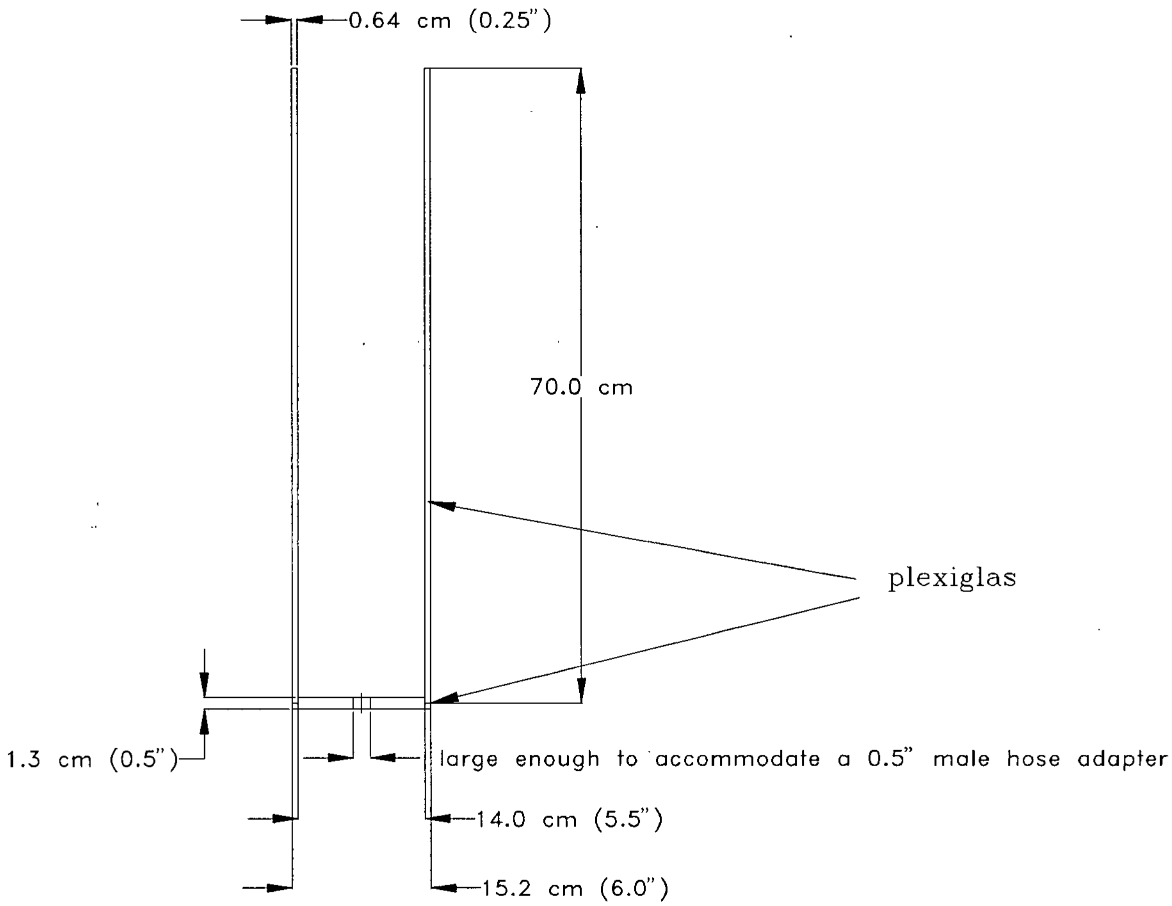

FIGURE 3. COLUMN DESIGN FOR '45 cm' COLUMN

of the leaching columns. In the field, tailings had been dug from soil pits and had been bagged into separate large plastic bags according their depths (at 15 cm intervals). The soil texture of the tailings in the different layers in listed in Appendix J.

Before the tailings were loaded into the soil columns, they were homogenized by hand down to clumps of 2 cm in diameter. At his stage, the 0-15 cm tailings were moist (9-13% water content), the 15-60 cm tailings were wet (20-31% water content), and the 60-90 cm tailings were very wet (29-36% water content). After homogenization, tailings equivalent to 15 cm in height were weighed out separately for every column and every layer. The weighed out tailings were packed into the columns in 1-2 cm intervals with a square wooden block (12" X 2" X 2"). The final bulk density of the tailings in the columns was 1000 to 1100 kg/m^3 compared to a field bulk density of 1150 to 1450 kg/m^3 (15-30 cm layer).

In leaching run 2, the tailings were slightly tapped into place in the columns as described above but under 1 to 2 cm of distilled water to speed up the saturation phase.

Most but not all column layers were 15 cm thick. The thickness varied between 11.5 and 16 cm; however, all column layers testing tailings from the same site received the same amount of tailings.

After the lower layers of tailings (15-90 cm) had been loaded into the columns and before the tailings/biosolids mixture was added to the top, the soil columns were saturated with distilled water for a few weeks (2 weeks for run 1 and 4 weeks for run 2). In the saturation phase, the same amount of distilled water was added to all columns at the same time. Between 5 and 20 mm of water was added to columns at any one time. Once the added water had infiltrated into the columns, more water was added in the saturation phase. Water was added slowly to the columns through the spout of a typical watering can (garden supply).

In the saturation phase of the leaching experiments, added distilled water was infiltrating so slowly that after a certain amount of time it was assumed that the columns were saturated.

The assumption that soil columns were completely or almost saturated at the start of leaching run 1 was confirmed with the collection of 75 to 80% of the added distilled water as leachate in the column run. However, only 50 to 55% of added distilled water was collected as leachate in run 2 which either demonstrates the low permeability of the tailings or might be due to the possible incomplete saturation of the columns. For details on the quantity of leachate collected refer to Appendix C.

A 100% recovery of the added water was not expected as the biosolids tend to absorb water which either will be held or will slowly evaporate. Less than 100% recovery of added water was also expected due to periods of standing water on top of the columns, some of which likely evaporated. An evaporation column of the same diameter was set up to estimate an upper bound for water lost during the leaching runs due to evaporation. In leaching run 1, evaporation from the evaporation column was 54 mm or 30% of the added water. In run 2, the evaporation from the evaporation column was 64 mm or 40% of the added water.

During the saturation phase in the second leaching run, column H started to become a special case ('45 cm' column with 100 dt/ha of biosolids) as approximately one third of the tailings filled into the column eroded out of the column. This was likely due to preferential pathways in the column. Despite that an effort was made to 'plug the holes' by pushing tailings contained in column H into the holes with a steel rod (1 cm in diameter), column H continued for most of the leaching run to release particulates into the leachate.

After the saturation phase, biosolids were weighed out separately for every test column. The biosolids alone would have been about 1.6 cm, 4.8-5.0 cm, or 14.4-15 cm high in the soil columns for the tested application rates of 30, 100, and 300 dt/ha respectively.

The weighed out biosolids were mixed by hand in a small wash basin with previously weighed out tailings from the 0-15 cm layer. The mixing of upper layer tailings and biosolids was done separately for every column and every pot and once mixed, the tailings/biosolids mixture was carefully loaded into the appropriate column or pot. The mixing of biosolids and tailings by hand is equivalent to very intensive rotovating in the field.

After all columns or pots were completely loaded, water for the first day in the first simulated 2-Day storm was added to all columns or pots.

3.5 Emptying of Soil Columns

At the end of leaching run 1, soil columns were emptied out by tapping the columns on a clean sheet of plastic on the floor and by cutting off the tailings mass as it came out at 15 cm intervals. Duplicate soil samples of the 15 cm intervals were then bagged into water-tight plastic bags, and the filled bags were stored in the refrigerator at 4°C for further homogenization and analysis. The samples were approximately 750 cm^3 in size.

At the end of leaching run 2, soil columns were emptied out by blowing the tailings slowly out of the columns with compressed air while the columns laid on their side on a clean sheet of plastic. Again, duplicate soil samples were cut off in 15 cm intervals and bagged in plastic bags for further homogenization and analysis. This process was fast and worked very well in only leaving a thin film of residue on the sides of the Plexiglas columns. Duplicate samples were also collected from the pots.

3.6 Sample Collection and Data Analysis - Leaching Experiments

In general, the record keeping and analysis of samples were more intensive in the second leaching run compared to the first leaching run except for the leachate analysis.

Samples that were analyzed for NO_3-N were also analyzed for nitrite (NO_2-N). In the discussion of results, NO_3-N plus NO_2-N concentrations are referred to as NO_3-N concentrations since all NO_2-N concentrations were less than 5% of the NO_3-N concentrations.

Prior to starting the leaching runs, representative samples of the tailings used in different layers were analyzed for TKN, NO_3-N, NO_2-N, and NH_4-N (in duplicate), and 4 to 5 samples of the biosolids used were analyzed for the concentrations of TKN, NH_4-N, NO_3-N, NO_2-N, arsenic (As), cadmium (Cd), chromium (Cr), cobalt (Co), copper (Cu), lead (Pb), mercury (Hg), molybdenum (Mo), nickel (Ni), selenium (Se), and zinc (Zn).

At the end of the first leaching run, the concentrations of TKN, NH_4-N, NO_3-N, and NO_2-N were determined with single samples for most layers and columns, and with duplicate samples for the 0-15 and 15-30 cm layers for columns with 100 and 300 dt/ha biosolids. If the measured concentrations were much higher or lower than was expected or than was measured in other columns with the same application rates, the concentration for these samples were determined anew in duplicate. Then, if all concentrations measured for a column layer were in the same range, the geometric mean was assumed to be the sample concentration. If the majority of the samples were in the same range, but one of the concentrations was much lower or much higher than the other concentrations, that concentration was assumed to be an outlier and was not considered in average calculations for the sample concentration.

In leaching run 2, all TKN concentrations were determined with duplicate samples for the 0-15 and 15-30 cm layers and with a single sample in the lower layers. All NO_3-N, NO_2-N, and NH_4-N concentrations were determined with duplicate samples for the 0-15, 15-30, and 30-45 cm layers and with single samples in the lower layers. If the concentrations measured differed greatly or were higher or lower than in other columns of same application rate and at the same layer depth, those samples were run again in duplicate. The final sample concentrations were determined according to the rules mentioned in the previous paragraph.

At the end of both leaching runs, metal concentrations were determined in the shortest and longest columns for the 0, 100, and 300 dt/ha application rates (for the 0-15, 15-30, and 30-45 cm layers).

For both leaching runs, leachate was collected and analyzed on 3 days per week for most weeks (first three days of every week or first three days after water additions). Weekly NO_3-N and NO_2-N concentrations were averaged from three measurements done on leachate collected on Days 1, 2, and 3 with a Technicon Autoanalyzer II equipped with a cadmium reduction column. Weekly TKN concentrations were averaged from two measurements done on leachate collected on Days 1 and 2 with a Technicon Autoanalyzer II. Weekly total P (TP) concentrations, and pH and electrical conductivity (EC) were determined manually for composite samples collected on Days 1, 2, and 3 of every week.

Leachate samples were analyzed directly for NO_3-N, NO_2-N, pH, and EC and were digested for the determination of TKN (sulfuric acid digestion) and Total P (nitric and sulfuric acid digestion). The element concentrations were determined colorimetrically for NO_3-N, TKN, and Total P. More details about laboratory methods used are included in Appendix O.

The determination of the element concentrations in soil or biosolids samples included either a digestion or extraction phase before the determination phase. Prior to digestion or extraction, soil and biosolids samples were homogenized by hand and only small subsamples were used for further analysis.

In the soil or biosolids analyses, the < 2 mm fractions were analyzed for: TKN by sulfuric acid digestion, NH_4-N, NO_3-N, and NO_2-N by 1 or 2 M potassium chloride extraction, Total P by nitric and sulfuric acid digestion, Hg by cold vapor atomic absorption, Se by hydride atomic absorption, and all other metals by aqua regia digestion and ICP analysis. Digestions or extraction were followed by a colorimetric determination of concentration for TKN, NO_3-N, NO_2-N, NH_4-N, and Total P. More details about laboratory methods are included in Appendix O.

The soil temperatures were measured automatically every two hours in 10 soil columns (at 10-15 cm depth) with thermocouplers that were connected via an A/D interface to a computer.

3.7 Methods of Data Analysis

All data collected was statistically analyzed with SAS software using the General Linear Models (GLM) procedure. The SAS software 'procedure GLM' does not require a balanced experimental design to statistically compare the results of different treatments. Note that running the GLM procedure with a two parameter factorial model for an unbalanced design is equivalent to running a two-way analysis of variance (ANOVA) on the data set of a balanced design. All statistical analysis was conducted at the 0.05 level of probability.

In the field trial, the design was unbalanced because only the application rate of 77 dt/ha biosolids was repeated, and in the leaching experiments, the design was unbalanced due to the replication of the 300 dt/ha application rate for the long columns.

In the data analysis, 'procedure GLM' was either run with a factorial model with interactions or with the main effects model. Whenever enough data was available, the factorial model was used because its outcome is statistically more sound than the main effects model for two or more parameters. The interpretation of results generated by a factorial or main effects model is discussed below.

As a rule of thumb, the degrees of freedom for the error in statistical models should be 30 or greater. In that case, the conclusion that can be drawn from the analysis are well supported as long as the data set contained representative data. The typical degrees of freedom for the error term (or DF for error) in the analysis of field data were below 10 and often only 1 or 2, meaning that conclusions that can be drawn from the tailings analysis are weakly supported. However, a statistical comparison with a model makes the identification of differences between treatments easier than comparing treatments without that tool. The degrees of freedom of the error term in a model can be increased with more observations for the same experimental parameters.

3.7.1 Factorial Model

In general, the factorial model y=(Parameter 1)|(Parameter 2) with interactions determines if there is significant difference between the treatments for every parameter in the model and if there is a significant interaction between these parameters.

In cases where the interaction term is not significant and where there is a significant difference between the treatments for one or more of the parameters, a simple functional relationship exists between the two parameters. Knowing the value of one parameter, say total metals added to soil, one can estimate the other parameter, say total concentration of metals in soil after application.

In cases where there is a significant interaction between the parameters in a factorial model, the values of both parameters have to be known to estimate the final outcome. For example, the tailings analysis determined significant interaction terms for NH_4-N concentrations at different application rates and times. The concentration of NH_4-N in soil tended to be higher in the early spring than later in the growing season. Thus, both the time of sample collection and the application rate influenced NH_4-N concentrations.

3.7.2 Main Effects Model

The main effect model determines if there is a direct relationship between one or more of the parameters in the model and the measured outcome in the experiment. If none of the parameters in the main effects model are significant, the analysis is complete.

Less certain is the interpretation of a parameter that is significant in the main effects model for two or more parameters. In that case, an interaction may or may not exist between the parameters in the model. Certainty about parameter interactions can only be established through the collection of more data and testing with a factorial model.

4.0 DISCUSSION OF RESULTS - LEACHING EXPERIMENTS

In the discussion of results, laboratory observations, soil nutrient concentrations, soil pH, EC, and soil metal concentrations are discussed before the leachate quality. To allow for easy comparison between the results of the two leaching runs, the same group of parameters is discussed first for leaching run 1 and then for leaching run 2 before comparing the next group of parameters.

In the leaching experiments discussed here, a tailings/biosolids mixture was added on top of previously saturated columns followed by repeated additions of distilled water. During the leaching experiments, unsaturated zones might have formed in the columns which might have led to an underestimation of NO_3-N leaching. However, since the field conditions in Princeton (a semi-arid zone) are not expected to be in a saturated state for long periods of the year, the conclusions drawn from the leaching experiments are expected to be representative of field conditions.

In the discussion of results, the Level of Detection (LOD) refers to the lowest concentration of analyte that an instrument could detect and that could be statistically differentiated from the background signal. Typically, the LOD is the mean of replicate blank signals plus 3 times the standard deviation of low level replicates (99% confidence that the analyte was actually detected). However, concentrations close to the LOD are only qualitatively detected. In the discussion of results, the Limit of Quantification (LOQ) refers to the concentration of analyte above which quantitative results may be obtained with a specified degree of confidence. Typically, the LOQ is the mean of replicate blank signals plus 10 times the standard deviation of low level replicates (30% accuracy).

In the data analysis, if concentrations were below the detection limit, half the detection limit was assumed to be the sample concentration.

4.1 Laboratory Observations

The permeability of the tailings was overestimated in the design calculations in which the tailings were assumed to be coarser than was measured in the laboratory. Nitrate movement through coarse tailings can be fast and far. Particle size distribution measurements showed that layers in the 0-90 cm layer consisted of silt, silty clay, silty clay loam, or silty loam with estimated coefficients of permeability ranging from 8.2E-05 m/s to 1.0E-10 m/s. Run 2 laboratory records of the drainage of standing water on top of the control columns led to the calculation of a coefficient of permeability of 2.5E-08 m/s (0.002 m/day) when assuming Darcy's Law for vertical flow and falling head (Eq. 2). This observation seems to be confirmed by field results which showed that mineral N moved downwards at approximately 15 cm per growing season (~0.001 m/day). Lesser downward movement of water is expected in the field compared to the laboratory since in the field, water evapotranspires. For information concerning the particle size distribution and coefficients of permeability, refer to Appendix J and for field data refer to Appendix M.

In general, the duplicate soil NO_3-N and NH_4-N concentrations did not fluctuate as much as the TKN concentrations which was likely due to the greater sample sizes for the NO_3-N and NH_4-N analyses (10-11 g) compared to the TKN analysis (1-3 g).

The heights of the standing water measured on top of the leaching columns in the first weeks of the second leaching run were interesting. In general, the shortest columns drained faster than the longer columns followed by columns that received the highest application rates of biosolids confirming the high capacity of biosolids to absorb water. By Day 40 all columns were dry. Refer to Appendix C for details.

During leaching run 2, the structural instability of four of the soil columns was noticed. Two of these soil columns were control columns (A and F) and two were short treatment columns (G and H). In these four columns, surface cracks tended to develop which eroded when water was added to the soil columns. It appears that biosolids in the other columns provided greater aggregate stability and mulching on top of the soil columns since no or little surface cracking was noticed. During leaching run 2, erosion of tailings out of columns A, F, G, and H ranged from 1-20 g particulates per collection of turbid leachate. The occurrence of particulates in the leachate is detailed in Appendix C.

4.2 Nitrogen, pH and Electrical Conductivity in Soil

In general, the variation between columns which underwent the same treatment was greater than anticipated in the experimental design phase. The statistical analysis was helpful in identifying trends in the element concentrations but in hindsight higher replication of the experiment would have been advised. The statistical analysis consisted of a factorial analysis with the two parameters 'column length' and 'application rate'. The data analysis was conducted for every 15 cm layer separately, but due to fewer long columns, the results for the layers below 45 cm are less well supported than results for the upper column layers.

The results of N balance calculations were similar for both leaching column runs and the pot trial and are therefore discussed together in section 4.4.

4.2.1 Nitrogen, pH, and EC in Soil - Leaching Run 1

In leaching run 1, levels of TKN, NH_4-N, NO_3-N, and EC were significantly different for either application rate or column length in some of the layers, but the soil pH was unaffected by the treatments. An overview of the results is shown in Table 4 and detailed information is included in Appendix D.

As expected, the concentration of TKN increased significantly in the 0-15 and 15-30 cm layers with application rate. For the 30 dt/ha application rate, the TKN concentration increased in the 0-15 cm

TABLE 4. SOIL NITROGEN, pH, EC - RUN 1

DEPTH		1:2 pH	1:2 EC (dS/m)	TKN (mg/kg)	NH4-N (mg/kg)	NO3-N (mg/kg)
0 - 15 cm	Mean	7.3	APPL sig.	APPL sig.	41.2	APPL sig.
	Std. Dev.	0.2			125.6	
15 - 30 cm	Mean	7.5	APPL sig.	APPL sig.	LENGTH	14.6
	Std. Dev.	0.2			sig.	14.2
30 - 45 cm	Mean	7.6	APPL sig.	41.7	14.6	APPL and
	Std. Dev.	0.2		32.9	31.5	LENGTH sig.
45 - 60 cm	Mean	7.5	0.3	19.5	3.0	0.2
	Std. Dev.	0.3	0.1	5.0	2.3	
60 - 75 cm	Mean	7.6	0.3	24.1	3.6	0.2
	Std. Dev.	0.1	0.1	8.9	1.7	
75 - 90 cm	Mean	7.6	0.4	21.9	APPL sig.	0.2
	Std. Dev.	0.1	0.1	5.2		

TKN (mg/kg)					
Depth / Appl.	# of Obs.	0 dt/ha	30 dt/ha	100 dt/ha	300 dt/ha
0 - 15 cm	26	22 c	490 c	1917 b	5502 a
15 - 30 cm	26	21 b	45 b	250 b	2243 a
30 - 45 cm	26	avg. value:	42		
45 - 60 cm	18	avg. value:	20		
60 - 75 cm	10	avg. value:	24		
75 - 90 cm	10	avg. value:	22		

NO3-N (mg/kg)					
Depth / Appl.	# of Obs.	0 dt/ha	30 dt/ha	100 dt/ha	300 dt/ha
0 - 15 cm	26	0.2 b	38 b	139 a	211 a
15 - 30 cm	26	avg. value:	15		
30 - 45 cm *	26	0.2 b	0.4 b	2.3 a	0.8 b
45 - 60 cm	18	avg. value:	0.2		
60 - 75 cm	10	avg. value:	0.2		
75 - 90 cm	10	avg. value:	0.2		

1:2 EC (dS/m)					
Depth / Appl.	# of Obs.	0 dt/ha	30 dt/ha	100 dt/ha	300 dt/ha
0 - 15 cm	26	0.1 c	0.4 c	1 b	2 a
15 - 30 cm	26	0.2 c	0.2 c	0.3 b	0.8 a
30 - 45 cm	26	0.2 c	0.2 c	0.3 b	0.4 a
45 - 60 cm	18	avg. value:	0.3		
60 - 75 cm	10	avg. value:	0.3		
75 - 90 cm	10	avg. value:	0.4		

*** The concentration of NO3-N is also dependent on the length of the columns.**

30-45 cm NO3-N (mg/kg):

Duncan Group.	Mean	N	LENGTH
a	1.9	8	_0-45 cm Col.
b	0.5	8	_0-60 cm Col.
b	0.4	10	_0-90 cm Col.

15-30 cm NH4-N (mg/kg):

Duncan Group.	Mean	N	LENGTH
a	78	10	_0-90 cm Col.
b	14	8	_0-60 cm Col.
b	13	8	_0-45 cm Col.

Notes:
'Std. Dev. ' refers to the sample standard deviation.
Means followed or preceded by the same letter are not significantly different at the 0.05 level of probability.
# of Obs. Number of observations in data set

layer whereas for the 100 and 300 dt/ha application rates, the TKN concentrations increased in the 0-15 and 15-30 cm layers with the highest increases in the 0-15 cm layer. In the 15-30 cm layer, the TKN concentrations were only significantly higher for the 300 dt/ha application rate.

The soil NO_3-N concentration varied significantly in the 0-15 and 30-45 cm layers. As expected, the NO_3-N concentration increased with increasing application rates in the 0-15 cm layer. In the 30-45 cm layer, the concentration of NO_3-N was dependent on the column length and application rate, but NO_3-N concentrations were low (< 2.3 mg/kg). Since column length is inversely related to better drainage, a higher concentration of NO_3-N in lower layers of shorter columns is not surprising.

The concentration of NH_4-N varied significantly with column length in the 15-30 cm layer and with application rates in the 75-90 cm layer. The NH_4-N concentration in the 15-30 cm layer increased with increasing column length. This result is likely due to decreased aeration caused by poorer drainage in the longer soil columns. The difference between the NH_4-N concentrations in the 75-90 cm layer were statistically significant as far as the numbers are concerned but since all the concentrations are below the Limit of Quantification (10 mg/kg), the analytical result is of little importance.

The high NH_4-N concentrations measured in the 0-15 cm layer for column 5 (445 mg/kg; '90 cm' column) and column 9 (416 mg/kg; '45 cm' column), both of which received 300 dt/ha biosolids were not statistically significant because the high NH_4-N concentrations were not repeated in the other columns of same column length and application rate.

The EC increased with increasing application rates but was comparable to the control columns for 30 dt/ha biosolids application rate. The EC decreased with depth as was expected. Assuming a factor of 2 for converting the 1:2 extraction EC to saturation extract EC, crops are not expected to be negatively affected for 30 and 100 dt/ha biosolids application rates, but sensitive crops may be affected by the 300 dt/ha application rate (Foth, 1984).

4.2.2 Nitrogen, pH, and EC in Soil - Leaching Run 2

At the end of the second leaching run, the levels for Loss on Ignition (LOI), TKN, NH_4-N, NO_3-N, and pH varied significantly for the application rates tested. Table 5 shows an overview of LOI, N, and soil pH and EC results and Appendix E includes further details for leaching run 2.

As expected, the percentage of organic matter in the soil columns increased with increasing application rates in the 0-15 cm layer for all application rates and in the 15-30 cm layer for the highest application rate (300 dt/ha). As the dry density of the biosolids is lower than the dry density of the tailings, the biosolids tended to float up to the 0-15 cm layer for the highest application rates even if they had been distributed evenly at the start of the leaching run. Therefore, the %LOI in the 0-15 cm layer was usually higher than the %LOI in the 15-30 cm layer for the 300 dt/ha application rate. For the 0, 30, 100 and 300 dt/ha application rates of freshly dewatered anaerobically digested biosolids, the %LOI is approximately 1.2, 2.5, 5.0, and 11.1 respectively in the 0-15 cm layer, and 1.1, 1.8, 3.4, and 9.9 respectively in the 0-30 cm layer.

As expected, the TKN concentration increased with increasing application rates in the 0-15 cm layer and was significantly higher in columns with 300 dt/ha biosolids in the 15-30 and 30-45 cm layers. The absolute TKN concentrations were higher for the 30, 100 and 300 dt/ha application rates than for the 0 dt/ha application rate in the 15-30 and 30-45 cm layers.

The concentrations of NH_4-N and NO_3-N in the 0-45 cm layer were interesting. In the columns in leaching run 2, the absolute concentrations of NH_4-N increased with increasing application rates in the 15-30 and 30-45 cm layers whereas NO_3-N increased with increasing application rates in the 0-15 cm layer. For NH_4-N, the statistical increase in the 15-30 and 30-45 cm layers was significant for the 100 and 300 dt/ha application rates and comparable for the 0 and 30 dt/ha application rates. In the pot trial, the NH_4-N concentration was only significantly higher for the 300 dt/ha application rate and the

TABLE 5. SOIL NITROGEN, pH, EC - RUN 2

DEPTH:		1:2 pH	1:2 EC (dS/m)	Loss on Ignition (%)	TKN (mg/kg)	NH4-N (mg/kg)	NO3-N (mg/kg)
0 - 15 cm	Mean	7.3	2.0	APPL sig.	APPL sig.	90.4	APPL sig.
	Std. Dev.	0.2	1.3			87.2	
15 - 30 cm	Mean	7.5	1.3	APPL sig.	APPL sig.	APPL sig.	102.1
	Std. Dev.	0.2	1.0				143.6
30 - 45 cm	Mean	APPL sig.	0.6	n/a	APPL sig.	APPL sig.	25.7
	Std. Dev.		0.3				40.2
45 - 60 cm	Mean	7.5	0.5	n/a	28.6	8.2	0.7
	Std. Dev.	0.1	0.3		21.1	18.2	1.0
60 - 75 cm	Mean	7.4	0.6	n/a	20.0	2.6	0.4
	Std. Dev.	0.1	0.3		11.2	2.4	0.5
75 - 90 cm	Mean	7.4	0.7	n/a	13.6	1.7	0.1
	Std. Dev.	0.1	0.5		8.3	1.2	0.0
Pot Trial	Mean	n/a	n/a	APPL sig.	APPL sig.	APPL sig.	APPL sig.

Loss on Ignition

Depth / Appl.	# of Obs.	0 dt/ha	30 dt/ha	100 dt/ha	300 dt/ha
0 - 15 cm	19	1.2 d	2.5 c	5 b	11 a
15 - 30 cm	21	1 b	1.1 b	1.8 b	8.7 a
Pot Trial	10	0.7 d	2.4 c	5.8 b	11.2 a

TKN (mg/kg)

Depth / Appl.	# of Obs.	0 dt/ha	30 dt/ha	100 dt/ha	300 dt/ha
0 - 15 cm	26	52 d	725 c	2252 b	4791 a
15 - 30 cm	26	40 b	151 b	583 b	4401 a
30 - 45 cm	26	26 b	30 b	69 b	386 a
45 - 60 cm	18	avg. value:	29		
60 - 75 cm	10	avg. value:	20		
75 - 90 cm	10	avg. value:	13.6		
Pot Trial	10	27 c	516 c	1925 b	5008 a

NH4-N (mg/kg)

Depth / Appl.	# of Obs.	0 dt/ha	30 dt/ha	100 dt/ha	300 dt/ha
0 - 15 cm	26	avg. value:	90.4		
15 - 30 cm	26	1 c	46 c	255 b	723 a
30 - 45 cm	26	1 c	6 bc	39 b	251 a
45 - 60 cm	18	avg. value:	8.2		
60 - 75 cm	10	avg. value:	2.6		
75 - 90 cm	10	avg. value:	1.7		
Pot Trial	10	1 b	3.2 b	5 b	19.1 a

NO3-N (mg/kg)

Depth / Appl.	# of Obs.	0 dt/ha	30 dt/ha	100 dt/ha	300 dt/ha
0 - 15 cm	26	0.1 c	235 bc	702 ab	928 a
15 - 30 cm	26	avg. value:	102		
30 - 45 cm	26	avg. value:	25.7		
45 - 60 cm	18	avg. value:	0.7		
60 - 75 cm	10	avg. value:	0.4		
75 - 90 cm	10	avg. value:	0.1		
Pot Trial	10	9 c	247 b	295 b	615 a

30-45 cm 1:2 pH:

Duncan Grouping		Mean	N	APPL
a		7.8	8	_300 dt/ha
b		7.5	6	_100 dt/ha
c	b	7.4	6	_ 30 dt/ha
c		7.3	6	_ 0 dt/ha

Notes:
'Std. Dev. ' refers to the sample standard deviation.
Means followed or preceded by the same letter are not significantly different at the 0.05 level of probability.
\# of Obs. Number of observations in data set

NO_3-N concentration tended to increase with increasing application rates, but was comparable for the 30 and 100 dt/ha application rates.

The almost complete conversion of NH_4-N to NO_3-N in the 0-15 cm layer demonstrates that the soil surface is much better aerated than are lower layers. It is noteworthy that the average NO_3-N concentrations in the 0-15 cm layer tended to be 300 to 400 mg/kg lower for the pots than for the soil columns for the 100 and 300 dt/ha application rates. The lower concentration of NO_3-N in the pots may be a result of droughty conditions. Since the pots drained easily after every water addition, the pots tended to dry out completely (air-dry) between water additions, especially when the water additions were weeks apart. In contrast, the soil surface in the soil columns needed longer to dry out since the tailings were draining poorly.

The pH varied significantly in the 30-45 cm layer with the highest pH measured for the highest application rate which seems surprising since soil pH tends to decrease with increased nitrification. Since the absolute differences between the pH levels measured were small, the difference in pH in the 30-45 cm was probably due to variations in the tailings between columns rather than between treatments.

4.3 Mineral Nitrogen

4.3.1 Mineral Nitrogen - Leaching Run 1

In leaching run 1, the available (mineral) N tended to increase with increasing application rates except for the '60 cm' columns filled with tailings from site 1 (P3a-R3) in which the mineral N content was lower for the 300 dt/ha columns than the 100 dt/ha columns. The highest measured mineral N content in the 0-45 cm layer was 745 kg N/ha. Details of the mineral N that was available in the soil columns of leaching experiment 1 are included in the Laboratory Data section of Appendix D.

Note that in leaching run 1, the measured background NH_4-N concentrations were higher than were measured in the field for similar tailings (see Appendix M). The results seemed to be systematic for the first leaching run and may be the result of NH_4-N contamination of the KCl extractant (KCl salt) that was used for the first run. The actual background NH_4-N concentrations for run 1 were probably less than 1 mg/kg.

4.3.2 Mineral Nitrogen - Leaching Run 2

Although mineral N in the 0-45 cm layer increased with increasing application rates in both leaching runs, much more mineral N was available in the second leaching run compared to the first leaching run. While in the first leaching run mineral N ranged from 200 to 745 kg/ha, mineral N in the second leaching run ranged from 1200 to 3000 kg N/ha for the 300 dt/ha application rate. Mineral N details are shown in Table 6 or can be found in the laboratory data section of Appendix E. The difference in mineralization rates between the column runs is discussed in section 4.4.

The higher mineral N contents in leaching run 2 compared to run 1 are likely due to better mineralization and nitrification conditions, as the soil surfaces of the columns were allowed to dry out between water additions in the latter stages of the run. The drying periods likely facilitated better aeration and hence contributed to better nitrification conditions.

In leaching run 2, the mineral N concentrations varied between 1050 and 2100 kg N/ha for the 100 dt/ha application rate and between 1300 and 3000 kg N/ha for the 300 dt/ha application rate. The high variation measured in the 90 cm duplicate columns 4 and 5, and D and E (300 dt/ha) was surprising. In the 0-45 cm layer, the mineral N contents for columns 4 and 5 were 2200 and 1300 kg N/ha respectively and for columns D and E the mineral N contents were 1800 and 3000 kg N/ha respectively. This wide variation stresses the importance of high replication of the experimental setup

TABLE 6. MINERAL N IN SOIL - LEACHING EXPERIMENTS

COLUMN TRIALS (0-45 cm PROFILE)								
			LEACHING RUN 1			LEACHING RUN 2		
Col.:	Column Length:	Appl. Rate:	NH4-N	NO3-N	NH4-N + NO3-N	NH4-N	NO3-N	NH4-N + NO3-N
	(cm)	(dt/ha)	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)
C1	0-90	0	23	3	25	6	1	7
C2	0-90	30	81	5	86	71	552	623
C3	0-90	100	191	340	531	542	539	1081
C4	0-90	300	361	264	625	900	1345	2245
C5	0-90	300	671	14	684	1037	293	1329
C6	0-45	0	17	2	19	6	1	7
C7	0-45	30	21	113	134	95	349	444
C8	0-45	100	70	268	338	502	1669	2170
C9	0-45	300	459	286	744	1003	232	1235
C10	0-60	0	17	1	18	13	1	14
C11	0-60	30	32	130	162	75	183	257
C12	0-60	100	67	245	311	533	790	1323
C13	0-60	300	103	206	309	1606	751	2356
C-A	0-90	0	17	1	18	6	0	6
C-B	0-90	30	65	95	161	50	708	758
C-C	0-90	100	91	140	231	429	946	1374
C-D	0-90	300	260	189	449	815	1009	1824
C-E	0-90	300	200	314	515	1289	1716	3005
C-F	0-45	0	14	1	15	9	0	10
C-G	0-45	30	23	44	67	27	752	779
C-H	0-45	100	12	146	157	240	940	1180
C-I	0-45	300	99	135	234	879	443	1321
C-J	0-60	0	12	1	13	7	0	7
C-K	0-60	30	12	6	18	143	239	382
C-L	0-60	100	18	184	202	710	632	1342
C-M	0-60	300	48	269	316	1037	714	1751

POT TRIAL (0-15 cm PROFILE)			
Appl. Rate:	NH4-N	NO3-N	NH4-N + NO3-N
(dt/ha)	(kg/ha)	(kg/ha)	(kg/ha)
0	< 3	11	< 14
30	8	316	324
30	2	326	328
30	1	248	249
100	8	355	363
100	6	437	443
100	6	336	342
300	26	974	999
300	25	870	894
300	34	875	909

and demonstrates the high variability of the mineralization and nitrification rates under virtually the same conditions.

At the end of the second leaching run, the mineral N available in the pots was about 60 mg/kg higher for the 30 dt/ha application rate and 600 and 200 mg/kg lower for the 100 and 300 dt/ha application rates respectively (0-15 cm layer). In the pots, the available N content was probably less than in the columns due to droughtier conditions in the latter weeks of run 2 (below 80-90% water filled soil pores). However, the available N in the pots was much higher than in the first leaching run likely due to the different water regime in the second leaching run, better aeration in the pots (better drainage), and the longer experimental phase.

In the pot trials, almost all mineral N was available in the form of NO_3-N as was most of the available N in the columns in the 0-15 cm layer. This result stresses the importance of appropriate N fertilizer application rates for well drained soils since NO_3-N not only leaches faster (hence further), but also constitutes the majority of available N.

4.4 Soil Nitrogen Balance - Leaching Experiments

An approximate soil N balance was calculated for all columns in leaching runs 1 and 2 and the pot trial. In the N balance calculations, the tailings background N and N at the end of the runs were calculated from dry weight nutrient concentrations in a soil layer multiplied by the amount of material in that layer using equations 3 or 4 (see below). The amount of N added to the columns or pots was determined from the TKN, NH_4-N, and NO_3-N dry weight concentrations in biosolids multiplied by the amount of biosolids added per column. The total soil N was assumed to be the sum of TKN and NO_3-N (kg N/ha). Refer to Table 7 for a summary of results of the N balance calculations. More details are included in Appendix D for leaching run 1 and Appendix E for leaching run 2 and the pot trial.

$$x \frac{\text{kg N}}{\text{ha*15 cm}} = \frac{y \text{ mg N}}{\text{kg}} * \frac{z \text{ kg}}{\text{(15 cm layer)}} * \frac{652315.7 * 153.3 \text{ cm}^2}{\text{ha}} * \frac{1}{10^6} \quad \textbf{Eq. 3}$$

where

x amount of N per hectare in a 15 cm layer [kg N/ha]
y concentration of the parameter determined with one of the methods specified in Appendix O [mg/kg]
z dry weight of the tailings or tailings/biosolids mixture in a 15 cm layer
z = (wet weight)*(1 - Soil Moisture [%]/100) [kg]

153.3 cm^2 = inside surface area of the soil columns

$$x \frac{\text{mg N}}{\text{column}} = \frac{y \text{ mg N}}{\text{kg}} * \frac{z \text{ kg}}{\text{(45 cm layer)}} \quad \textbf{Eq. 4}$$

where

x amount of N per 45 cm layer [mg N/(45 cm layer)]
y concentration of the parameter determined with one of the methods specified in Appendix O [mg/kg]
z dry weight of the tailings or tailings/biosolids mixture in a 45 cm layer
z = (wet weight)*(1 - Soil Moisture [%]/100) [kg]

The absolute N balance numbers differed between the leaching experiments, but all experiments showed a similar trend. At the end of the leaching runs, the absolute amount of N lost and the absolute amounts of total N in the columns increased with increasing application rates. However, separate statistical comparisons for data collected in the two columns runs and the pot trial revealed that N losses were only significantly higher for the 300 dt/ha application rate indicating high variations between columns with the same treatment. Generally, the N losses were much higher than was anticipated by the author.

For the highest biosolids application rate (300 dt/ha), the N losses were substantial (30-34%) and were coupled with low retention of mineral N in the soil. For the 300 dt/ha application rate, likely contributors to this result were anaerobic conditions in the 15-30 cm layer resulting from high biological activity in the 30 cm thick tailings/biosolids layer, and mineralization and nitrification in the surface layer. Nitrate close to the soil surface could have easily denitrified after the addition of water to the columns and the temporary creation of anoxic conditions.

TABLE 7. SOIL NITROGEN BALANCE - LEACHING EXPERIMENTS

Application Rate (dt/ha):			0	30	100	300
Added N :	**Run1**	**(mg N/(45 cm layer))**	0	1643	5477	16432
	Run2	**(mg N/(45 cm layer))**	0	1927	6421	19265
	Pot Trial	**(mg N/(15 cm layer))**	0	1927	6421	19265
Soil N at Start:	**Run1**	**(mg N/(45 cm layer))**	138 d	1781 c	5612 b	16551 a
	Run2	**(mg N/(45 cm layer))**	233 d	2135 c	6643 b	19507 a
	Pot Trial	**(mg N/(15 cm layer))**	66 d	1995 c	6494 b	19349 a
Soil N at End:	**Run1**	**(mg N/(45 cm layer))**	129 c	1263 c	4577 b	11647 a
	Run2	**(mg N/(45 cm layer))**	175 d	2001 c	6107 b	13634 a
	Pot Trial	**(mg N/(15 cm layer))**	66 c	1408 bc	4337 b	12711 a
Soil N lost:	**Run1**	**(mg N/(45 cm layer))**	9 b	518 b	1036 b	4904 a
	Run2	**(mg N/(45 cm layer))**	57 b	134 b	536 b	5874 a
	Pot Trial	**(mg N/(15 cm layer))**	0 b	587 b	2157 b	6638 a
% of Added N lost:	**Run1**	**(mg N/(45 cm layer))**		32%	19%	30%
	Run2	**(mg N/(45 cm layer))**		7%	8%	30%
	Pot Trial	**(mg N/(15 cm layer))**		30%	34%	34%

Notes:
The data analysis was conducted separately for column runs 1 and 2 (26 observations) and the pot trial (10 observations).
Means followed by the same letter are not significantly different at the 0.05 level of probability.

Other likely contributing factors to the high N losses were: good mixing of the tailings with the biosolids (higher mineralization rate), no vegetation cover that could take up available N or could impede volatilization, optimal pH for mineralization and nitrification, relatively warm soil temperatures (> 14°C, avg. ~17.5°C), and relatively high concentration of bacteria in the biosolids at the time of application. Anaerobic bacteria, like methanogens which were present in biosolids at the time of application and which established during the anaerobic digestion treatment process (14-17 days retention time), likely mineralized N anaerobically, especially in the first few weeks of the experiments.

On average, the total N losses in the column studies were lower in the second leaching run than in the first leaching run, however, most N was lost in the pot trial. Furthermore, the relative N losses were even greater for the pots than the columns because the N balance calculations included the 0-45 cm layer for the leaching columns and the 0-15 cm layer for the pot trial.

In the column runs, the majority of N losses were probably due to denitrification followed by volatilization losses and small leaching losses. As mineral N was mainly in the form of NO_3-N in the 0-15 cm layer (at the end of the runs), the addition of water to the columns likely changed the aerobic conditions to anoxic conditions which in the presence of NO_3-N and organic C create excellent conditions for denitrification. Volatilization losses were probably responsible for higher N losses in the early stages of the experiment, especially in the mixing phase of tailings and biosolids which was an odoriferous undertaking, and in the first few weeks of the runs with standing water on top of the soil columns (simulation of spring melt conditions). Volatilization losses throughout the remainder of the runs were probably smaller as NO_3-N dominated the 0-15 cm layer. Generally, NH_4-N volatilization from soil is highest when the soil moisture content is near field capacity and when slow drying conditions exist for several days (Tisdale et al., 1993).

In the pot trial, denitrification and NO_3-N leaching were likely responsible for the biggest N losses followed by volatilization. Since most of the available N in the pots was in the form of NO_3-N at the end of the run, the addition of water could have created temporarily anoxic conditions which could have favoured denitrification. Possibly, NO_3-N leaching was substantial due to the high NO_3-N concentrations in the pots and good drainage. The extent of NO_3-N leaching cannot be quantified as no leachate was collected for analysis from the pots. Volatilization losses were likely larger at the start compared to the end of the pot trial due to the 11% NH_4-N content of TKN in the biosolids.

To be able to compare and assess the mineralization behaviour of biosolids added to copper tailings, an overview table based on the soil data was created that details the percentile distribution of the added total N at the end of the run. The overview table, Table 8, shows the percent of added N in the form of soil mineral N, the percent of N that was lost (unaccounted N), and the estimated mineralization rates at the end of the leaching runs.

Higher than expected were the mineralization rate and the amount of N lost from the soil columns. For example, the U.S. EPA (1983) assumes that about 20% of the organic N contained in biosolids mineralizes in the soil and that 10 to 15% unaccountable N losses occur in the first year after application. In this study, the average estimated mineralization rates ranged from 17 to 31% over 10 weeks for column run 1, from 29% to 38% over 13 weeks for column run 2, and from 30 to 43% over 13 weeks for the pot trial. These higher mineralization rates are likely due to the same beneficial conditions for mineralization and nitrification that were mentioned in the previous paragraphs discussing factors contributing to high N losses.

There appeared to be a trend towards either low mineral N content in the soil and high N losses or higher retention of mineral N in the soil and lower N losses. For example, for the 300 dt/ha application rate, the mineral N in soil ranged from 2-6% in column run 1, from 10-24% in column run 2, and from 7-8% in the pot trial whereas the N losses ranged from 12-51% for column run 1, from 26-37% for column run 2, and from 22-42% for the pot trial.

In the leaching columns, errors in estimating the N content in columns could have been introduced by under- or overestimating the amount of material contained in soil layers or by erring in the laboratory analysis. In the laboratory, especially the over- or underestimation of soil TKN could have occurred since only small sample sizes were used for the highest application rates (1-2 g). To confirm N concentrations measured in the leaching tests, additional samples were analyzed for the 30, 100, and 300 dt/ha application rates and 0-15 and 15-30 cm layers (one sample per column and layer), but the concentrations tended to be all of the same order of magnitude as had been measured previously.

TABLE 8. PERCENT OF ADDED NITROGEN AS MINERAL N AND UNACCOUNTED N

COLUMN TRIALS (0-45 cm PROFILE)								
			LEACHING RUN 1			LEACHING RUN 2		
Col.:	Column Length:	Appl. Rate:	% of Added N as Mineral N in soil	% of Added N lost	Estimated Mineralization Rate of Organic N	% of Added N as Mineral N in soil	% of Added N lost	Estimated Mineralization Rate of Organic N
	(cm)	(dt/ha)						
C2	0-90	30	8%	27%	25%	50%	1%	39%
C3	0-90	100	15%	7%	12%	26%	13%	27%
C4	0-90	300	6%	19%	15%	18%	30%	36%
C5	0-90	300	6%	12%	8%	11%	37%	36%
C7	0-45	30	13%	32%	34%	35%	21%	45%
C8	0-45	100	9%	25%	24%	52%	2%	42%
C9	0-45	300	7%	15%	12%	10%	28%	26%
C11	0-60	30	15%	4%	9%	20%	9%	18%
C12	0-60	100	9%	22%	20%	32%	13%	33%
C13	0-60	300	3%	14%	7%	19%	29%	36%
C-B	0-90	30	15%	41%	46%	60%	1%	50%
C-C	0-90	100	6%	26%	22%	33%	5%	26%
C-D	0-90	300	4%	43%	37%	15%	28%	31%
C-E	0-90	300	5%	44%	39%	24%	26%	38%
C-G	0-45	30	6%	39%	35%	62%	0%	50%
C-H	0-45	100	4%	4%	-2%	28%	0%	17%
C-I	0-45	300	2%	51%	43%	11%	34%	33%
C-K	0-60	30	2%	46%	37%	30%	10%	29%
C-L	0-60	100	6%	29%	24%	32%	10%	30%
C-M	0-60	300	3%	41%	34%	14%	31%	33%

POT TRIAL (0-15 cm PROFILE)				
Appl. Rate:	% of Added N as Mineral N in soil	% of Added N lost	Estimated Mineralization Rate of Organic N	
				Average
(dt/ha)				
30	26%	22%	36%	
30	26%	30%	44%	43%
30	20%	39%	47%	
100	9%	33%	30%	
100	11%	25%	24%	31%
100	8%	42%	38%	
300	8%	22%	18%	
300	7%	42%	37%	30%
300	7%	40%	35%	

COLUMN TRIALS (0-45 cm PROFILE)		
Appl. Rate:	Estimated Mineralization Rate of Organic N	
	RUN 1	RUN 2
(dt/ha)		
30	31%	38%
100	17%	29%
300	24%	34%

Estimated Mineral. Rate of Organic N in Biosolids = Mineral N in soil + N losses - (NH4-N in biosolids at the time of application) [%]

In general, variations in the data could probably have been made smaller by analyzing more samples per column and layer for TKN and NO_3-N to determine better individual estimates and by using larger samples sizes for the TKN analysis than was possible in the BIOE Lab. However, wide variations in the mineralization of organic N in biosolids after incorporation in soils have been mentioned in the literature (Williams et al., 1984; Sopper, 1993) which this study confirms, and high variations in column studies have also been mentioned by Elder (1988).

For future research, it is encouraging that the mineralization rates in column run 2 and the pot trial were similar. This result suggests that the mineralization of N can be studied in shorter soil columns which are much easier to set up and to keep in a controlled atmosphere than the longer columns.

In the author's opinion, the mineralization rate should be studied in more detail and under more controlled conditions. The samples sizes for the TKN measurement should be increased (at least doubled) and the digestion should be done in larger vessels.

4.5 Metals in Soil

In leaching runs 1 and 2, the metal concentrations in the 0-15, 15-30, and 30-45 cm layers were determined for the '45 cm' and '90 cm' columns only. The laboratory results were again compared with a factorial model using 'application rate' and 'column length' as parameters to determine significant differences between the treatments. Refer to Appendices F and G for laboratory and analytical results for leaching runs 1 and 2 respectively.

4.5.1 Metals in Soil - Leaching Run 1

In leaching run 1, the metal analysis of soil samples from the '45 cm' and '90 cm' columns showed that all metal concentrations were below the lowest of the CCME remediation criteria for agricultural or residential soils (1991) except for the Hg concentration in the 0-15 cm layer columns with 300 dt/ha biosolids and Cu in all tested layers. An overview of the data analysis in shown in Table 9 and for more details refer to Appendix F.

In leaching run 1, the only significant changes in the element concentration were measured in the 0-15 cm layer for Hg and Zn. The highest measured Hg concentration was 1.2 mg/kg which is above the CCME criterion for agricultural soils but below the CCME criterion for residential soils (1991) and clearly above the Limit of Quantification for Hg (0.6 mg/kg). According to Bohn et al. (1985), the Hg concentrations measured in the samples were above normal soil levels for the 100 and 300 dt/ha application rate in the 0-15 cm layer.

The concentration of Zn increased with increasing application rates of biosolids which is not surprising due to the higher concentration of Zn in the biosolids (621 mg/kg) compared to the tailings (69 mg/kg).

4.5.2 Metals in Soil - Leaching Run 2 (Soil Columns)

In leaching run 2, more significant differences for metal concentrations were identified than for leaching run 1 which may indicate a greater intrinsic uniformity of the tailings in run 2 than in run 1. In leaching run 2, metal concentrations in the soil columns were below the lowest of the CCME criteria for agricultural and residential use (1991) and were in the normal range for soils according to Bohn et al. (1985) with the exception of the Hg concentrations in the 0-15 and 15-30 cm layers for columns with 300 dt/ha biosolids and Cu concentrations in all layers and columns. Refer to Table 10 or Appendix G for details on run 2 metal concentrations.

In run 2, significant increases with increasing application rates were measured in the 0-15 and 15-30 cm layers for Pb, Hg, Se, and Zn whereas the Co concentration decreased with increasing application rates in the 15-30 cm layer. As expected, the highest metal increases were measured in the 0-15 cm

TABLE 9. TOTAL METALS IN SOIL - RUN 1

Depth		Arsenic	Cadmium	Chromium	Cobalt	Copper	Lead	Mercury	Molybd.	Nickel	Selenium	Zinc
		(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)
0 - 15 cm	Mean	< 8.0	0.7	41.6	16.0	1080	14.6	APPL sig.	0.7	18.9	0.6	APPL sig.
	Std. Dev.		0.3	3.8	1.2	71	3.1		0.2	2.2	0.3	
15 - 30 cm	Mean	< 8.0	0.4	50.6	18.0	1578	8.1	0.2	0.7	22.5	0.4	91.5
	Std. Dev.		0.2	2.2	1.6	169	4.7	0.1	0.2	2.1	0.1	9.0
30 - 45 cm	Mean	< 8.0	0.4	54.8	18.5	1528	4.1	< 0.1	0.6	24.5	0.3	88.8
	Std. Dev.		0.3	6.3	2.1	157	1.9		0.2	2.8	0.1	6.7
Normal Range *		1 - 50	0.01 - 7	5 - 1000	1 - 40	2 - 100	2 - 200	0.02 - 0.2	0.2 - 5	10 - 1000	0.1 - 2	10 - 300
Typical Concentration *		5	0.06	20	8	20	10	0.05	2	40	0.5	50
CCME **		20	3	250	40	100	375	0.8	5	100	2	500

Total Metal	Depth	Application Rate		
		0 dt/ha	100 dt/ha	300 dt/ha
Mercury	0-15 cm	0.1 c	0.5 b	1.2 a
Zinc	0-15 cm	69 c	107 b	163 a

Notes:
The factorial model with parameters APPL (application rate) and LENGTH (Column length) was run on the data.
The Duncan multiple range test at the 0.05 level of probability was used to determine significantly different means.
In the analysis, if the concentration measured was below the detection limit, half the concentr. of the detection limit was used in average calculations.
'Std. Dev. ' refers to the sample standard deviation.
Means followed by different letters are significantly different.

* Bohn et al., 1985
** Lowest of the remediation limits for agricultural or residential soils set by the Canadian Council of Ministers of the Environment (1991)

TABLE 10. TOTAL METALS IN SOIL - RUN 2

Depth		Arsenic (mg/kg)	Cadmium (mg/kg)	Chromium (mg/kg)	Cobalt (mg/kg)	Copper (mg/kg)	Lead (mg/kg)	Mercury (mg/kg)	Molybdenum (mg/kg)	Nickel (mg/kg)	Selenium (mg/kg)	Zinc (mg/kg)
0-15 cm	Mean	< 8.0	0.8	50.7	18.9	1613	APPL sig.	APPL sig.	1.4	21.6	APPL sig.	APPL sig.
	Std. Dev.		0.2	2.9	1.5	83			0.6	2.2		
15-30 cm	Mean	< 8.0	0.6	56.8	APPL sig.	1856	APPL sig.	APPL sig.	1.1	25.3	APPL sig.	APPL sig.
	Std. Dev.		0.2	6.2		210			0.5	2.1		
30-45 cm	Mean	< 8.0	0.5	62.5	24.6	2168	6.8	< 0.1	0.9	28.5	0.5	111.3
	Std. Dev.		0.2	5.8	2.1	476	5.5		0.5	3.1	0.1	16.2
Normal Range *		1 - 50	0.01 - 7	5 - 1000	1 - 40	2 - 100	2 - 200	0.02 - 0.2	0.2 - 5	10 - 1000	0.1 - 2	10 - 300
Typical Conc. *		5	0.06	20	8	20	10	0.05	2	40	0.5	50
CCME **		20	3	250	40	100	375	0.8	5	100	2	500

Total Metal	Depth	Application Rate 0 dt/ha	100 dt/ha	300 dt/ha
Lead	0-15 cm	6.8 c	11.8 b	27.8 a
	15-30 cm	5.6 b	6.8 b	21.0 a
Mercury	0-15 cm	0.1 c	0.3 b	0.9 a
	15-30 cm	0.1 b	0.1 b	0.5 a
Selenium	0-15 cm	0.4 c	0.7 b	1.4 a
	15-30 cm	0.5 b	0.6 b	1.2 a
Zinc	0-15 cm	82 c	120 b	182 a
	15-30 cm	106.3 b	112.3 b	152.6 a
Cobalt	0-15 cm	Average value:		18.9
	15-30 cm	24.3 a	24.0 a	19.5 b

Notes:
The Duncan multiple range test at the 0.05 level of probability was used to determine significantly different means.
'Std. Dev. ' refers to the sample standard deviation.
Means followed by different letters are significantly different.

* Bohn et al., 1985
** lowest of the remediation limits for agricultural or residential soils set by the Canadian Council of Ministers of the Environment (1991)

layer where the most of the biosolids had been incorporated except for 300 dt/ha columns in which biosolids had been incorporated evenly into the 0-15 and 15-30 cm layers.

In the 0-15 cm layer of the 300 dt/ha columns, the Hg concentration was only 0.1 mg/kg above the CCME (1991) remediation criterion for agricultural use and was below the CCME criterion for residential use. According to Bohn et al. (1985), the Hg concentration was above the normal levels for soils in the 0-15 cm layer for the 100 dt/ha application rate and the 0-15 and 15-30 cm layers for the 300 dt/ha application rate. Increasing Hg concentration with increasing application rates is not surprising since the tailings are low in Hg (~0.1 mg/kg) and the biosolids applied contained 5.7 mg/kg Hg.

4.6 Leachate Quality

Leachate was collected on a weekly basis from all soil columns in leaching runs 1 and 2. In general, the leachate was as clear as distilled water with exception of particulates in the leachate on some days for some columns. Refer to Appendix C for details on particulates in the collected leachate. Refer to Appendices H and I for detailed results for leaching runs 1 and 2 respectively. Information in Appendices H and I is arranged in the order of NO_3-N data analysis and laboratory results, TKN data analysis and laboratory results, total P laboratory results, and finally leachate pH and EC results.

Estimates of the total amounts of NO_3-N, TKN, and TP in the leachate are also included in the laboratory data sections of Appendices H and I. Total amounts of nutrients in the leachate were calculated by summing the products of (weekly nutrients concentrations) times (weekly leachate volume).

4.6.1 Leachate Quality - Leaching Run 1

4.6.1.1 Leachate Quality - Run 1 - Nitrate

The measured NO_3-N concentrations in the first leaching run were very low. The average NO_3-N concentration measured was 0.02 mg/L and the total amount of NO_3-N lost through leaching was less than 0.37 kg/ha. The highest daily maximum NO_3-N concentration was 2.1 mg/L which is well below the maximum NO_3-N concentration allowed in drinking water (10 mg/L). Thus in leaching run 1, the contribution of NO_3-N in leachate was negligible in the overall N balance. Refer to Table 11 or Appendix H for details on NO_3-N in leachate.

4.6.1.2 Leachate Quality - Run 1 - TKN

In leaching run 1, the average TKN concentrations measured were generally low (< 0.5 mg/L) for all weeks except weeks 4, 5, and 6 of the experiment. In these weeks, the TKN concentrations in the leachate tended to be higher for the short columns especially for the highest application rate (300 dt/ha). The highest weekly TKN concentration was 6.7 mg/L measured in week 6 for the '45 cm' columns with 300 dt/ha of added biosolids. The maximum daily TKN concentrations ranged from 0.1 to 24.9 mg/L with an average daily maximum concentration of 3.1 mg/L. In leaching run 1, the contribution of TKN in leachate to the overall N balance was greater than the NO_3-N contribution but was below 0.07% of the N added. Starting in week 4 of leaching run 1, the measured TKN concentration tended to be higher for the higher application rates. Refer to Table 12 or Appendix H for details.

The TKN concentrations in weeks 5 and 6 were higher than expected and are likely due to the build-up of preferential channels in the shorter soil columns after a few weeks of water additions. The preferential flow channels may have allowed the flow of small pieces of biosolids to the bottom of the columns and into the leachate collecting bottle, however, the leachate from the short 300 dt/ha columns (columns 9 and I) was as clear as distilled water. The one time measurement of 24.9 mg/L

TABLE 11. NITRATE IN LEACHATE - RUN 1

		R-Square	C.V. (%)	Std. Dev.	Mean
Total NO3-N/Column	(mg/col.)	0.419	267	0.13	0.05
Average NO3-N/Column	(mg/L)	0.419	201	0.04	0.02
Max. NO3-N/Col.	(mg/L)	0.379	238	0.49	0.21

TABLE 12. TKN IN LEACHATE - RUN 1

		R-Square	C.V. (%)	Std. Dev.	Mean
Total TKN/Column	(mg/col)	0.625	121	1.2	1.0
Max. TKN/Column	(mg/L)	0.302	177	5.5	3.1
Week 1 - TKN	(mg/L)	0.227	354	1.9	0.5
Week 2 - TKN	(mg/L)	0.446	162	0.3	0.2
Week 3 - TKN	(mg/L)	0.524	199	1.0	0.5
Week 4 - TKN	(mg/L)	APPL and LENGTH sig.			
Week 5 - TKN	(mg/L)	all values			< 2.7
		except for the Columns C-9 and C-I concentrations			
Week 6 - TKN	(mg/L)	all values			< 1.2
		except for the Columns C-9 and C-I concentrations			
Week 9 - TKN	(mg/L)	0.390	186	0.7	0.4

Average TKN concentrations		Column: Appl. Rate:	C-9 & C-I 300 dt/ha
Week 5 - TKN	(mg/L)		5.8
Week 6 - TKN	(mg/L)		6.7

Week 4 - TKN (mg/L):

Duncan Grouping		Mean	N	APPL
	a	1.2	8	_300 dt/ha
b	a	0.3	6	_ 30 dt/ha
b	a	0.3	6	_100 dt/ha
b		0.1	6	_ 0 dt/ha

Duncan Grouping	Mean	N	LENGTH
a	1.1	8	_0-45 cm Col.
b	0.3	10	_0-90 cm Col.
b	0.2	8	_0-60 cm Col.

Notes:
The Duncan multiple range test at the 0.05 level of probability was used to determine significantly different means.
Means followed or preceded by different letters are significantly different.
'Std. Dev. ' refers to the sample standard deviation, and N refers to the number of observations.

TKN for column E ('90 cm' column) appears high especially when considering the sluggish drainage of the longer columns. Therefore, this high concentration may be due to sampling or analytical errors in the laboratory.

4.6.1.3 Leachate Quality - Run 1 - Total Phosphorus

In leaching run 1, TP concentrations were all low. The highest weekly TP concentration was 1.7 mg/L measured for column 9 ('45 cm' column with 300 dt/ha biosolids). All other weekly TP concentrations were below 0.9 mg/L with weekly column averages ranging from 0.01 to 0.28 mg/L. The total amounts of P in the leachate were below 0.6 kg/ha for all columns. Refer to Appendix H for details on TP in leachate.

In general, the P determination caused a lot of extra laboratory work compared to the measurement of the other parameters in the BIOE Lab. The Stannous Chloride method used for determining P is very sensitive and sample contamination with P from lab benches, pipettes, or glassware was the cause of all initially high P measurements. When a high P concentration was measured in a sample, another two samples of the same leachate were digested and analyzed again with utmost care. No high P concentrations were confirmed in the repeated analyses.

Procedures to avoid P contamination errors included the duplicate washing of glassware and pipette tubes with phosphate free soap, followed by rinsing well with tap water and rinsing twice with distilled water. As well, all lab benches were washed twice before use. However, since the same laboratory benches, glassware, and pipettes were used for other projects analyzing high N and high P animal wastes, a slight contamination of the pipettes (top part) from other samples could have caused sample contamination.

4.6.1.4 Leachate Quality - Run 1 - pH and EC

The pH of the collected leachate varied little throughout the weeks of the experiment and the average pH ranged from 7.9 to 8.3. The highest variation in pH were measured for the control columns 10, F, and J in the last two weeks of the column study. The declining pH in these columns coincided with collection of turbid leachate during those weeks which is detailed in Appendix C. Turbid leachate indicates preferential flow of water in the soil columns so that instead of measuring the pH of water that travelled through the soil column, the pH measured might have been the pH of the added distilled water (5.5) that had been raised somewhat through contact with tailings in the soil columns.

The electrical conductivities measured in the soil columns ranged from 0.2 to 2.2 dS/m for individual weekly measurements and from 0.4 to 1.9 dS/m for overall column averages. The EC tended to increase from week to week and with increasing application rates. In the medium length columns, the EC tended to vary from week to week whereas the EC decreased for the longest columns over the run. Based on these results, it is expected that over time the EC will increase in the leachate for the longer soil columns once the leachate collected has travelled from the biosolids amended soil surface to the bottom of the soil columns. In general, the EC was lower for the shorter columns than for the longer columns indicating that ions are picked up by the percolating water from the tailings.

4.6.2 Leachate Quality - Leaching Run 2

4.6.2.1 Leachate Quality - Run 2 - Nitrate

The concentrations of NO_3-N in leachate were greater in the second leaching run than in the first leaching run. Overall, the higher NO_3-N concentrations are likely due to the different water regime in run 2 that allowed more N to mineralize and more NO_3-N to be formed, and due to the extended experimental phase. Run 2 was 13 weeks in length whereas run 1 was 10 weeks in length.

Notably high concentrations of NO_3-N were measured for the columns G and H in the last few weeks of the run (weeks 8, 9, 12, and 13). The highest daily concentrations measured for columns G and H were 1245 and 1076 mg NO_3-N/L respectively. However, the maximum daily NO_3-N concentrations for all other columns were below 2.4 mg/L which is well below the Canadian limit for drinking water (10 mg/L). For all columns except columns G and H, the contribution of NO_3-N to the overall N balance was negligible (< 0.4 kg/ha). Detailed results are shown in Table 13 and in Appendix I.

As NO_3-N concentrations for the '45 cm' columns G and H (30 and 100 dt/ha) were much higher than for the other columns, a separate data analysis was conducted on data collected for columns 1 through 13 (tailings from site 3) and columns A through M (tailings from site 4). Due to the low concentration of NO_3-N in most leachate samples and due to the low replication of the experiment (one DF for Error), the data analysis showed many significant interactions. However, the average weekly NO_3-N concentrations for columns 1 through 13 were below 1.7 mg/L. The average weekly NO_3-N concentrations for columns A through M with exception of columns G and H were below 1.2 mg/L.

Column H was a special case from the start of the second leaching run. While saturating column H, about one third of the material loaded into the column eroded out of the column into the leachate collection bottle. Due to their fine texture and their low organic matter and clay contents, the tailings possess little shear strength which makes them very susceptible to water erosion. Once one preferential flow channel exists in a leaching column, progressive concentration of flow in that channel can quickly lead to particle entrainment. Particle entrainment can cause localized scour and redistribution of particles in the channel which tends to increase the flow speed even more.

Leachate collection data show that particulates were collected from columns A, F, G, and H. Since the columns A and F were control columns, the particulates in these columns were not expected to increase the N concentrations in the leachate. However, the collection of particulates in soil column G

TABLE 13. NITRATE AND NITRITE IN LEACHATE - RUN 2

Results for columns loaded with site 3 tailings		R-Square	C.V.	Std. Dev.:	Mean:	Max.
Total NO3-N/Col.	(mg/col)	APPL, LENGTH, and APPL*LENGTH sig., but all values				< 0.3
Max. NO3-N/Col.	(mg/L)	APPL, LENGTH, and APPL*LENGTH sig., but all values				< 2.4
Week 1 - NO3-N	(mg/L)	APPL, LENGTH, and APPL*LENGTH sig., but all values				< 0.3
Week 2 - NO3-N	(mg/L)	APPL, LENGTH, and APPL*LENGTH sig., but all values				< 0.1
Week 3 - NO3-N	(mg/L)	APPL, LENGTH, and APPL*LENGTH sig., but all values				< 0.1
Week 4 - NO3-N	(mg/L)	0.521	79	0.01	0.02	
Week 5 - NO3-N	(mg/L)	APPL, LENGTH, and APPL*LENGTH sig., but all values				< 0.1
Week 8 - NO3-N	(mg/L)	APPL, LENGTH, and APPL*LENGTH sig., but all values				< 0.6
Week 9 - NO3-N	(mg/L)	APPL, LENGTH, and APPL*LENGTH sig., but all values				< 0.4
Week 12 - NO3-N	(mg/L)	APPL, LENGTH, and APPL*LENGTH sig., but all values				< 1.7
Week 13 - NO3-N	(mg/L)	APPL, LENGTH, and APPL*LENGTH sig., but all values				< 1.6

Results for columns loaded with site 4 tailings			Max.
Total NO3-N/Col.	(mg/col.)	APPL, LENGTH, and APPL*LENGTH sig., but all values except for Column C-G and C-H concentrations	< 0.6
Max. NO3-N/Col.	(mg/L)	APPL, LENGTH, and APPL*LENGTH sig., but all values except for Column C-G and C-H concentrations	< 1.9
Week 1 - NO3-N	(mg/L)	APPL, LENGTH, and APPL*LENGTH sig., but all values	< 0.2
Week 2 - NO3-N	(mg/L)	APPL, LENGTH, and APPL*LENGTH sig., but all values	< 1.2
Week 3 - NO3-N	(mg/L)	APPL, LENGTH, and APPL*LENGTH sig., but all values	< 0.5
Week 4 - NO3-N	(mg/L)	APPL, LENGTH, and APPL*LENGTH sig., but all values	< 0.7
Week 5 - NO3-N	(mg/L)	APPL, LENGTH, and APPL*LENGTH sig., but all values	< 0.4
Week 8 - NO3-N	(mg/L)	APPL, LENGTH, and APPL*LENGTH sig., but all values except for Column C-G and C-H concentrations	< 0.2
Week 9 - NO3-N	(mg/L)	APPL, LENGTH, and APPL*LENGTH sig., but all values except for Column C-G and C-H concentrations	< 0.3
Week 12 - NO3-N	(mg/L)	APPL, LENGTH, and APPL*LENGTH sig., but all values except for Column C-G and C-H concentrations	< 0.9
Week 13 - NO3-N	(mg/L)	APPL, LENGTH, and APPL*LENGTH sig., but all values except for Column C-G and C-H concentrations	< 0.6

Average NO3-N concentrations for Col. G and H (0-45 cm Columns):

Site 4 Tailings		Column G (30 dt/ha)	Column H (100 dt/ha)
Total NO3-N/Col.	(mg/col.)	188	121
Max. NO3-N/Col.	(mg/L)	1245	1076
Week 8 - NO3-N	(mg/L)	24	129
Week 9 - NO3-N	(mg/L)	32	49
Week 12 - NO3-N	(mg/L)	706	249
Week 13 - NO3-N	(mg/L)	819	693

(30 dt/ha) in weeks 8, 9, 12, and 13 and in soil column H (100 dt/ha) in weeks 2, 3, 8, 9, 12, and 13 may have contained biosolids that were washed from the soil surface into the collecting bottle. Unfortunately, only the surpernatant of the collected leachate with particulates was analyzed for NO_3-N and TKN, not the solid fraction. The particulates in the leachate were separated from the liquid fraction through centrifugation at 2000 r.p.m. for 20 minutes. In retrospect, the solids in the leachate should have been analyzed for NO_3-N and TKN as well to determine if or how much of the NO_3-N and TKN in the leachate may be attributed to sample contamination with biosolids which washed down from the surface.

The elevated concentrations of NO_3-N in leachate of columns G and H were confirmed by high soil concentrations of NO_3-N (see Appendix E) which were higher for these columns in the 15-30 and 30-45 cm layers than for any of the other columns with the same application rates. The higher soil concentrations of NO_3-N also support the idea that biosolids were washed from the surface to lower layers.

For column G, approximately 109% of the applied N was recovered at the end of the run of which 8.4% (123 kg/ha) was in the form of NO_3-N in leachate and 92% was in soil. Note that 109% of the applied N was recovered for column G indicating that the N balance calculations are approximate. For column H, approximately 102% of the applied N was recovered at the end of the run of which 1.9% (79 kg/ha) was in the form of NO_3-N in leachate.

4.6.2.2 Leachate Quality - Run 2 - TKN

In the second leaching run, the behaviour of the leaching columns differed again between tailings from sites 3 and 4. Similar to the second run NO_3-N concentrations, TKN concentrations in leachate were high for column H and elevated for column G. The highest daily maximum concentration was 249 mg TKN/L for column H and 5.6 mg TKN/L for column G. The average TKN concentrations per column were all below 1 mg/L except for column G (1.6 mg/L) and column H (46.2 mg/L). Refer to Table 14 or Appendix I for detailed information.

As discussed in the previous section, higher levels of TKN in the leachate of column G in weeks 4, 8, and 9, and in leachate of column H in weeks 2, 3, 4, 8, 9, and 12 are likely due to particulate matter that short-circuits the tailings in the soil columns via preferential flow channels.

The contribution of TKN in leachate to the overall N balance was negligible for all columns (< 1 kg/ha) except for column H. At the end of leaching run 2, approximately 102% of the applied N was recovered for column H of which 2.5% (103 kg/ha) was in the form of TKN in leachate, 1.9% (79 kg/ha) was in the form of NO_3-N in leachate, and the remainder was in soil.

4.6.2.3 Leachate Quality - Run 2 - Total Phosphorus

As expected, run 2 total P concentrations in leachate were all relatively low with the highest weekly concentration of 0.68 mg/L measured for column H. Again, the somewhat elevated TP concentration for column H could have resulted from biosolids that flushed from the surface soil into the collecting bottle. The average TP concentrations per column were all below 0.19 mg/L or drinking water quality. The contribution of P in leachate to the total P balance was less than 0.4 kg/ha and thus negligible. Details are included in Appendix I.

4.6.2.4 Leachate Quality - Run 2 - pH and EC

As in leaching run 1, the pH of the leachate did not change significantly for any of the columns. The average pH ranged from 7.8 to 8.3. The highest pH variation per column was measured for column H (4%) with the pH declining over the period of the leaching run to pH levels similar to the added biosolids. Refer to Appendix I for details on measurements of pH and EC.

TABLE 14. TKN IN LEACHATE - RUN 2

Results for columns loaded with site 3 tailings		R-Square	C.V. (%)	Std. Dev.	Mean	Max.
Total TKN/Column	(mg/col)	0.982	18	0.06	0.35	
Max. TKN/Column	(mg/L)	0.995	13	0.28	2.16	
Week 1 - TKN	(mg/L)	APPL, LENGTH, and APPL*LENGTH sig., but all values				< 0.6
Week 2 - TKN	(mg/L)	0.987	14	0.06	0.40	
Week 3 - TKN	(mg/L)	APPL, LENGTH, and APPL*LENGTH sig., but all values				< 0.6
Week 4 - TKN	(mg/L)	APPL, LENGTH, and APPL*LENGTH sig., but all values				< 3.5
Week 5 - TKN	(mg/L)	all values				< 0.2
Week 8 - TKN	(mg/L)	0.918	77	0.58	0.75	
Week 9 - TKN	(mg/L)	0.988	28	0.09	0.32	
Week 12 - TKN	(mg/L)	0.763	60	0.06	0.09	

Results for columns loaded with site 3 tailings		R-Square	C.V. (%)	Std. Dev.	Mean	Max.
Total TKN/Column	(mg/col.)	APPL, LENGTH, and APPL*LENGTH sig., but all values except for the Column C-H concentration				< 1.0
Max. TKN/Column	(mg/L)	APPL, LENGTH, and APPL*LENGTH sig., but all values except for the Column C-H concentration				< 5.6
Week 1 - TKN	(mg/L)	0.640	177	0.5	0.3	
Week 2 - TKN	(mg/L)	APPL, LENGTH, and APPL*LENGTH sig., but all values except for the Column C-H concentration				< 0.8
Week 3 - TKN	(mg/L)	APPL, LENGTH, and APPL*LENGTH sig., but all values except for the Column C-H concentration				< 0.2
Week 4 - TKN	(mg/L)	APPL, LENGTH, and APPL*LENGTH sig., but all values except for the Column C-H concentration				< 2.5
Week 5 - TKN	(mg/L)	all values				< 0.2
Week 8 - TKN	(mg/L)	APPL, LENGTH, and APPL*LENGTH sig., but all values except for the Column C-H concentration				< 5.6
Week 9 - TKN	(mg/L)	APPL, LENGTH, and APPL*LENGTH sig., but all values except for the Column C-H concentration				< 3.2
Week 12 - TKN	(mg/L)	0.992	63	0.3	0.4	

TKN concentration for Column H:

Site 4 Tailings		Column: C-H Appl. Rate: 100 dt/ha
Week 2 - TKN	(mg/L)	125
Week 3 - TKN	(mg/L)	155
Week 4 - TKN	(mg/L)	23
Week 8 - TKN	(mg/L)	10
Week 9 - TKN	(mg/L)	7

The electrical conductivities for columns filled with tailings from site 3 were generally 1 to 1.5 dS/m lower than for columns filled with tailings from site 4. The EC did not fluctuate much for columns filled with tailings from site 3 (columns 1 through 13) for individual columns but tended to be lower for the shorter columns than the longer columns (same behaviour as in run 1). The individual weekly electrical conductivities ranged from 0.6 to 1.2 dS/m and overall column averages ranged from 0.6 to 1.1 dS/m.

The electrical conductivities for columns filled with tailings from site 4 (columns A through M) ranged from 0.9 to 4.8 dS/m for individual weekly measurements and overall column averages ranged from 1.8 to 2.9 dS/m. Again, the overall column averages tended to be lower for the shorter columns than for the longer columns. The highest fluctuations in the EC per column were measured for column F (38%) and column H (61%). The high electrical conductivities in column H in week 2 (4.8 dS/m) and week 3 (3.4 dS/m) were possibly due to direct contamination of the leachate with biosolids and/or NO_3-N or NH_4-N flushed into the collecting bottle during those weeks.

4.7 Sampling and Analytical Errors in the Leaching Experiment

Like all data, the laboratory data had associated systematic and random errors. Systematic errors can be traced to a cause while random errors result from many different causes and their effects can be minimized by collecting and averaging more comparable data.

In the leaching experiments, probably the largest error was a random error in the TKN analysis, followed by under- or overestimation of the bulk density of the material in the columns. In the leaching runs, the concentration of TKN varied significantly between duplicated samples (average 16%; highest 37%) likely due to small sample sizes used in the analysis (2-3 g for low concentration and ~1 g for high concentration samples). An extra morsel of biosolids in TKN samples could have increased the sample concentration significantly since the biosolids have a high TKN concentration and weigh about one quarter of the tailings.

It would have probably been better to digest larger sample sizes to reduce this error. The possibility of digesting larger sample sizes in the Bio-Resource Engineering Laboratory was rejected due to space limitation in the fume hood and due to too few heating elements for larger digestion flasks. The author believes that the larger flasks (800 mL) that were used by the GVRD Laboratory were a better approach to determining TKN concentrations for soil samples in this project. Due to the uncertainty in the TKN results, the interpretation of the TKN and Total N concentrations in the leaching experiments are somewhat limited. However, since the same procedure and apparatus were used for all samples, the author believes that the laboratory results represent the conditions in the leaching columns well enough for interpretation.

An erroneous estimation of the bulk density of tailings in the columns could have increased or decreased the estimated nutrient content per hectare. Errors could have occurred by assuming that soil was packed to the same thickness throughout the columns. To avoid errors of this kind, the weight, moisture content, and layer thickness were measured at the time of loading, and the soil moisture and layer thickness were determined at the time of unloading. In retrospect, the weight of the material in every layer and every column should have been determined at the time of unloading to increase the accuracy of the results.

Other errors include contamination errors during the emptying of the columns or during the laboratory analysis. In the emptying process, tailings from the bottom of the column had to move past areas previously occupied by biosolids and contamination of the lower samples with biosolids left on the edges of the soil columns might have occurred. However, both the methods of emptying the columns left only a fine film of tailings on the surface thus reducing this contamination error.

In the NO_3-N analysis, the Limit of Detection (LOD) rose during the leaching runs. The LOD of the newly purchased and installed cadmium reduction column at the beginning of run 1 was 0.01 to 0.02 mg NO_3-N/L whereas the detection limit at the end of the leaching run 2 was 0.1 to 0.3 mg NO_3-N/L. A decline in column sensitivity is normal for cadmium reduction columns, especially for small columns (3 cm long, 10 windings) sold for the Technicon Autoanalyzer II. The higher LOD in run 2 automatically leads to higher average concentrations as the half of the LOD is assumed to be the concentration of samples below the detection limit.

5.0 SUMMARY OF MAIN RESULTS - LEACHING EXPERIMENTS

As a reminder, column run 1 was conducted under generally wetter conditions than column run 2 and the pot trial. The pot trial was conducted under the same environmental conditions as the column run 2, however, the pots were very well drained. The 0, 30, 100, and 300 dt/ha application rates of freshly dewatered biosolids were investigated.

Nitrogen, pH and Electrical Conductivity in Soil

As expected, the TKN concentration and the organic matter content increased with increasing application rates in the 0-15 cm layer.

The concentrations of NH_4-N and NO_3-N in the 0-45 cm layer were interesting. The absolute concentrations of NH_4-N in the columns were higher in 15-30 layer (and 30-45 cm layer in run 2) whereas NO_3-N tended to increase with increasing application rates in the 0-15 cm layer.

It is noteworthy that the average NO_3-N concentrations in the 0-15 cm layer tended to be 300 to 400 mg/kg lower for the pots than for the soil columns for the 100 and 300 dt/ha application rates. The lower concentration of NO_3-N in the pots may be a result of droughty conditions.

The surface pH did not change significantly in the leaching experiments.

The EC tended to increase with increasing application rates, and the growth of salt sensitive crops may be slowed on plots amended with 300 dt/ha biosolids.

Mineral Nitrogen in Soil

Although mineral N in the 0-45 cm layer increased with increasing application rates in both leaching runs, much more mineral N was available in the second leaching run compared to the first leaching run. While in the first leaching run the mineral N ranged from 200 to 745 kg/ha (1.9-7.0% of added N), the mineral N in the second leaching run ranged from 1200 to 3000 kg N/ha (9.5-24.0% of added N) for the 300 dt/ha application rate.

At the end of the second leaching run, the mineral N available in the pots was about 60 mg/kg higher for the 30 dt/ha application rate and 600 and 200 mg/kg lower for the 100 and 300 dt/ha application rates respectively (0-15 cm layer). However, the available N in the pots was much higher than in the first leaching run likely due to the different water regime in the second leaching run, better aeration in the pots (better drainage), and the longer experimental phase.

Nitrogen Balance

The absolute N balance numbers differed between the leaching experiments, but all experiments showed a similar trend. At the end of the leaching runs, the absolute amount of N lost and the absolute amounts of total N in the columns increased with increasing application rates. Nitrogen losses were only significantly higher for the 300 dt/ha application rate indicating high variations between columns with the same treatment.

For the highest biosolids application rate (300 dt/ha), the N losses were substantial (30-34%) and the mineral N retention in the soil was low. There appeared to be a trend towards either low mineral N content in the soil and high N losses, or higher retention of mineral N in the soil and lower N losses.

On average, the total N losses in the column studies were lower in the second leaching run than in the first leaching run; however, most N was lost in the pot trial. Likely contributing factors to the high N losses and high mineralization rate were: good mixing of the tailings with the biosolids (higher mineralization rate), no vegetation cover that could take up available N or could impede volatilization, optimal pH for mineralization and nitrification, relatively warm soil temperatures (> 14°C, avg. ~17.5°C), and relatively high concentration of bacteria in the biosolids at the time of application.

Higher than expected were the mineralization rate and the amount of N lost from the soil columns. The average estimated mineralization rates ranged from 19 to 35% over 10 weeks for column run 1, from 33 to 43% over 13 weeks for column run 2, and from 34 to 48% over 13 weeks for the pot trial.

Similar mineralization rates for the pot trial and the second column run suggest that the mineralization of N can be studied in shorter soil columns which are much easier than longer columns to set up and keep in a controlled atmosphere.

Total Metals

In leaching runs 1 and 2, metal concentrations in the soil columns were below the lowest of the CCME criteria for agricultural and residential use (1991) with the exception of the Hg concentrations in the upper layers for columns with 300 dt/ha biosolids and the Cu concentrations in all layers and columns. However, all Hg concentrations were below the residential soil criterion.

Leachate Quality - Leaching Run 1

The measured NO_3-N concentrations in the first leaching run were very low with an average NO_3-N concentration of 0.02 mg/L and the highest amount of NO_3-N lost through leaching of 0.37 kg/ha.

In leaching run 1, the average TKN concentrations measured were generally low (< 0.5 mg/L) for all weeks except weeks 4, 5, and 6 of the experiment. In those weeks, the TKN concentrations in the leachate tended to be higher for the short columns especially for the highest application rate (300 dt/ha). The highest weekly average TKN concentration was 6.7 mg/L measured in week 6 for the '45 cm' columns with 300 dt/ha of added biosolids.

In leaching run 1, TP concentrations were all low. The highest weekly TP concentration was 1.7 mg/L, and the P in leachate was below 0.6 kg/ha for all columns.

In leaching run 1, the pH of the collected leachate varied little throughout the experiment and with the average pH ranging from 7.9 to 8.3. The electrical conductivities of the leachate were low and ranged from 0.2 to 2.2 dS/m for individual weekly measurements and from 0.4 to 1.9 dS/m for overall column averages.

Leachate Quality - Leaching Run 2

The NO_3-N concentrations in leachate were greater in the second leaching run than in the first leaching run likely due the different water regime that allowed more N to mineralize and nitrify in run 2, and due to the extended experimental phase.

Notably high concentrations of NO_3-N were measured for the columns G and H in weeks 8, 9, 12, and 13 of the experiment. The highest daily concentrations measured for columns G and H were 1245 and 1076 mg NO_3-N/L respectively. However, the maximum daily NO_3-N concentration for all other columns were below 2.4 mg/L which is well below the Canadian limit for drinking water (10 mg/L).

For all columns except columns G and H, the contribution of NO_3-N to the overall N balance was negligible (< 0.4 kg/ha). For column G, approximately 8.4% (123 kg/ha) of added N was in the form of NO_3-N in leachate. For column H, approximately 1.9% (79 kg/ha) of added N was in the form of NO_3-N in leachate.

In leaching run 2, TKN concentrations in leachate were high for column H and elevated for column G. The highest daily maximum concentrations were 249 mg TKN/L for column H and 5.6 mg TKN/L for column G. The TKN level in leachate was below 0.6 kg/ha for all columns except for column H with 103 kg/ha (2.5% of added N).

In leaching run 2, total P concentrations in leachate were all relatively low with the highest weekly concentration of 0.68 mg/L measured for column H. The average TP concentrations per column were all below 0.19 mg/L or drinking water quality.

The high NO_3-N and TKN concentrations in leachate of columns G and H, and the elevated TP concentration in leachate of column H may be due to the preferential flow of percolating water. Furthermore, column H was a special case from the start of the second leaching run since about one third of the material loaded into the column eroded out of the column in the saturation phase.

In leaching run 2, the pH of the leachate did not vary greatly and ranged from 7.8 to 8.3. The electrical conductivities for columns filled with tailings from site 3 ranged from 0.6 to 1.1 dS/m and were generally 1 to 1.5 dS/m lower than for columns filled with tailings from site 4.

6.0 METHODS AND MATERIALS - FIELD EXPERIMENT

6.1 Plot Treatments

In October 1992, biosolids were applied to six tailings plots of which four 0.5 ha plots are discussed in this thesis as they were studied in more detail. The biosolids were applied with hydraulic ram manure spreaders at application rates of 62, 77 (two plots), and 179 dt/ha (55000, 69000, and 160000 lb/acre respectively). Subsequently, the biosolids were incorporated with a 20 cm (8") farm disk, and the demonstration sites were seeded with a no-till, seed-drill seeder and rolled (680 kg roller) to minimize seed loss through wind erosion. A nurse crop seed mix was seeded at 30 kg/ha and a reclamation seed mix was seeded at 65 kg/ha. The field application rates are given in Table 15 and the characteristics of the biosolids and the seed mix are shown in Tables 16 and 17 while treatments are depicted in Figure 4. Photographs of the field trial are included in Appendix P (Figures 5-10).

The original project design was based on the application of freshly dewatered biosolids throughout, but stored dewatered biosolids were applied on most plots since not enough freshly dewatered biosolids were available at the time of transport. Furthermore, a switch from stored dewatered to land-dried biosolids took place on the unfinished plot 2b (northern 1/3 of 2b) due to odor complaints from residents. Stored dewatered biosolids were approximately 6 months old and contained about 3.4% total N of which 42 % was in the form of NH_4-N at the time of application whereas land-dried biosolids contained approximately 1.1% total N of which 2.3% was in the form of NH_4-N. The switch to land-dried biosolids introduced another variable into the study. Application rates were not adjusted to compensate for the lower N content of the land-dried biosolids.

The biosolids were applied as homogeneously as was possible with manure spreaders. The biosolids were flung off the drums of manure spreaders in clumps of 2 to 10 cm in diameter. These clumps, once distributed on the tailings, were somewhat broken up and incorporated into the tailings by the disking operation, but the drill seeding and rolling of the tailings after disking also compacted and flattened some clumps on the surface. This effect was more pronounced for portions of plots 3a and

TABLE 15. BIOSOLIDS TREATMENTS - FIELD EXPERIMENT

Plot	Site Conditions	Plot size (ha)	Application Rate (dt/ha)	Biosolids type
2a	Tailings without vegetation	0.5	77	Stored dewatered
2b	Tailings without vegetation	0.5	62	41 dt/ha Stored dew. & 21 dt/ha Land-dried
3a	Tailings without vegetation	0.5	179	Stored dewatered
3b	Tailings without vegetation	0.5	77	Stored dewatered

TABLE 16. BIOSOLIDS CHARACTERISTICS - FIELD EXPERIMENT

	Field Experiment		B.C. Draft Guidelines for the Disposal of Domestic Sludge (1983)	
Element:	Annacis Land-dried Dewatered Biosolids Oct-92	Annacis Stored Dewatered Biosolids Oct-92	Agricultural Low Grade	Retail High Grade
Total Kjeldahl N (mg/kg)	~ 11000	33785	-	-
% Moisture	31	74.9	-	< 70.0
Nitrate/Nitrite-N (mg/kg)	101	5	-	
Ammonium-N (mg/kg) - extracted	241	12072	-	-
Ammonium-N (mg/kg) - distilled	266	16733	-	-
Arsenic (mg/kg)	< 12	< 17.0	75	75.0
Cadmium (mg/kg)	1	5.0	25	5-20
Chromium (mg/kg)	40	50.0	-	-
Cobalt (mg/kg)	5.0	4.1	150.0	150.0
Copper (mg/kg)	219	1050	-	-
Lead (mg/kg)	88	190	1000	500
Mercury (mg/kg)	3	6.7	10	5.0
Molybdenum (mg/kg)	< 4	6.6	20	20.0
Nickel (mg/kg)	31	37	200	180
Selenium (mg/kg)	1	6.0	14	14.0
Zinc (mg/kg)	193	915	2500	1850

TABLE 17. SEED MIX USED IN THE PRINCETON DEMONSTRATION PROJECT

Reclamation Mix:		
20%	BOREAL Creeping Red Fescue	*Festuca rubra*
15%	Hard Fescue	*Festuca ovina var. duriuscula (L.) Koch*
10%	CARLTON Bromegrass	*Bromus inermis*
10%	STREAMBANK Wheatgrass	*Agropyron riparium Scribn. & Smith*
10%	FAIRWAY Crested Wheatgrass	*Agropyron cristatum (L.) Gaertn.*
5%	Canada Bluegrass	*Poa compressa L.*
5%	ALMA Timothy	*Phleum pratense L.*
10%	RANGELANDER Alfalfa	*Medicago sativa L.*
5%	White Clover	*Trifolium repens L.*
5%	SC Red Clover	*Trifolium pratense L.*
5%	CICER Milkvetch	*Astragalus cicer L.*
Nurse Crop Seed Mix:		
67%	Fall Rye	*Secale cereale*
33%	Hairy Vetch	*Vicia villosa*

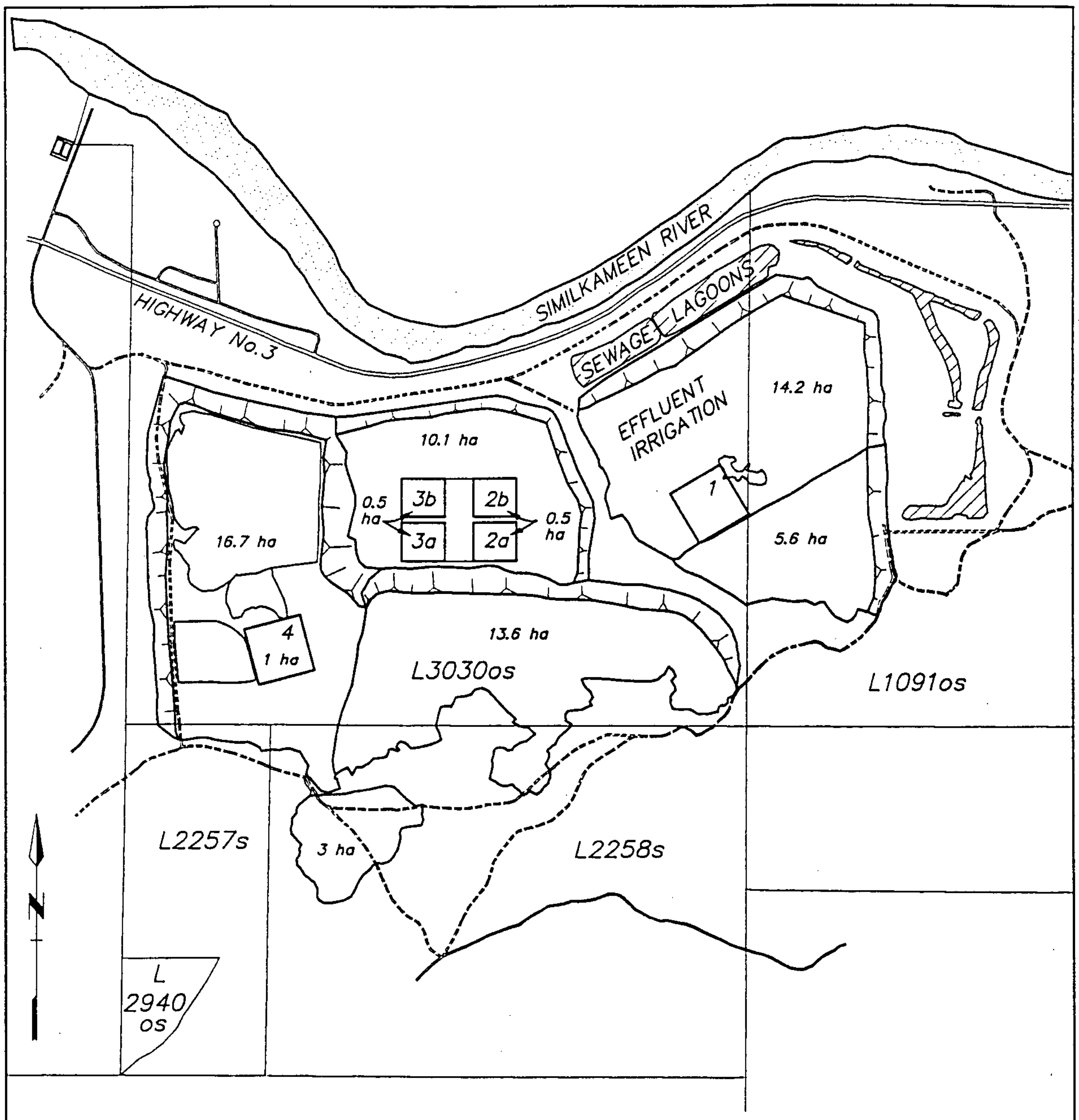

FIGURE 4. LOCATION OF FIELD SITES IN PRINCETON, B.C. (1992-1993)

3b due to higher application rates. Micro-site application rates varied between zero and approximately twice the specified application rate.

6.2 Soil Sample Collection and Analysis

Composite soil samples were collected prior to, and 6 and 12 months after biosolids application from the 0-15, 15-30, 30-60, 60-90, 90-120, and 120-150 cm soil layers. Care was taken to collect representative soil samples by collecting 10-15 subsamples per plot from the 0-15 and 15-30 cm layers and 5 subsamples for the lower spoil layers. Composite soil samples were either collected with a 0.5" (1.3 cm) or 1" (2.5 cm) soil probe attachment using a JMC Backsaver Handle Soil Probe (Clements Associates Inc.). Half of the probe part of the JMC probe is open to the surrounding environment to allow easy access to soil cores. To avoid contamination of soil samples, about one third to one half of every soil sample in the probe (the portion that was open to the surrounding soil) was wasted. The remainder of every soil sample was collected in water-tight plastic bags.

Despite the effort that was made to collect representative composite samples, there might have been a sampling bias in the upper layers due to the sampling procedure. The sampling probe had a tendency to part the biosolids on the soil surface rather than core them, leading to lower nutrient and organic matter results than had been expected. A discussion of the problems encountered during soil sampling and recommendations for future projects is included in section 7.6.

All composite soil samples were analyzed for the parameters: TKN, NO_3-N (NO_3-N + NO_2-N), NH_4-N, and total P. In addition, composite soil samples from sites 2a and 3a were analyzed for the elements: As, Cd, Co, Cr, Cu, Hg, Mo, Ni, Pb, Se, and Zn. Soil fertility was also assessed for all 0-15 cm soil samples. Soil fertility analyses included the parameters: pH, EC, NH_4-N, NO_3-N (NO_3-N + NO_2-N), Bray P-1, potassium (K), calcium (Ca), magnesium (Mg), boron (B), Cu, Zn, iron (Fe), manganese

(Mn), sulfate, organic matter, and CEC. Discrete soil samples (0-15 cm layer) collected in April 1993 were also analyzed for Olsen-P in the BIOE Lab.

In the original design, three discrete samples were to be collected from all treatment sites to estimate the variations in biosolids application and treatment effects. To lower the project costs, this design was changed from 3 to 2 discrete samples for one of the sites with the duplicated biosolids application rate (77 dt/ha). However, instead of duplicating the application rate 77 dt/ha on sites 2a and 2b, the field applicator applied 77 dt/ha to sites 2a and 3b leading to the collection of only 2 discrete background samples for plot 2b (62 dt/ha).

Discrete samples were collected from the 0-15, 15-30, 30-45, 45-60, and 60-90 cm layers at the same time as composite soil samples were collected. Discrete soil samples were collected with trowels from edges of 90-100 cm deep soil pits. The samples were analyzed for TKN, NH_4-N, NO_3-N (NO_3-N + NO_2-N), total P, and metals.

To minimize errors resulting from local site differences, discrete samples were collected repeatedly from the same two to three discrete areas per treatment site. The discrete areas were approximately 5m X 5m in size and the samples were labelled: Site_Name - R1, Site_Name - R2, and Site_Name - R3. The previously sampled sites in a discrete area were marked so that they would not be sampled again. This sampling technique was based on the assumption that the collection of discrete samples from the 'same' area over time establishes treatment differences better than the collection of randomly located discrete samples at every sampling event.

Once a soil sample was collected, the sample was stored in a cooler in the field and in a refrigerator once delivered to a laboratory (at 4°C). The samples were analyzed for the various parameters as quickly as possible by established laboratories.

In the soil analyses, the < 2 mm fractions were analyzed for: TKN by sulfuric acid digestion, NH_4-N and NO_3-N by 1 or 2 M potassium chloride extraction, exchangeable K, Ca, and Mg by NH_4-N acetate extraction, total P by sulfuric and nitric acid digestion, available P by Bray P-1 extraction (composite samples) and by Olsen-P extraction (April 1993 discrete samples), sulfate by calcium chloride extraction, available Zn, Fe, Cu, and Mn by DTPA-TEA extraction, B by hot water extraction, organic matter by total carbon determination (org. matter = TC*1.78), Hg by cold vapor atomic absorption, Se by hydride atomic absorption, and all other metals by aqua regia digestion and ICP analysis. Digestions or extraction were followed by a colorimetric determination of concentration for TKN, NO_3-N, NH_4-N, total P, Bray P-1, and B; by turbidimetric determination for sulfate; or by atomic absorption spectrophotometry (A.A.S) for exchangeable K, Ca, and Mg, and available Zn, Fe, Cu, and Mn. More details about laboratory methods are included in Appendix O.

6.3 Vegetation Samples and Data Collection

Vegetation samples were collected in July and September 1993 of which July samples were used to estimate species establishment and September samples were statistically compared. In July 1993, composite vegetation samples were collected from areas of low vegetation establishment and high vegetation establishment. The density of vegetation cover on the treatment plots was classified into areas of low and high vegetation establishment by visual inspection. Sketches of the density of vegetation cover were made for every plot at the time of sample collection to estimate the yield per hectare. In July 1993, at least 3 subsamples were collected for every composite sample per plot and classification (low and high vegetation establishment). The sampling areas for the low and high vegetation areas were 4 m^2 and 0.5 m^2 respectively. For the low vegetation areas, composite sampling continued until about 1000 cm^3 of vegetation had been cut. The vegetation was cut about 4-5 cm above the ground.

In September 1993, vegetation was collected from five discrete, predetermined locations per treatment (pattern '5' on a die). The vegetation was cut from 0.25 m^2 areas about 4-5 cm above the ground. However, only one of the samples from plot 3a yielded enough vegetation for analysis. The samples were analyzed for TKN, NO_3-N (NO_3-N + NO_2-N), NH_4-N, yield, As, Cd, Cr, Cu, Pb, Hg, Mo, Ni, Se, and Zn. From the control plot, three discrete samples were collected which were analyzed separately for TKN and NO_3-N and were composited for metal and yield analyses. Species within the discrete vegetation samples were not analyzed separately.

Vegetation clippings were not washed before analysis so that Cu concentrations in vegetation samples might have been elevated due to the adherence of Cu tailings to plant samples resulting from air-borne particulates from surrounding untreated tailings. Vegetation samples were sealed in plastic bags and kept in coolers in the field (at approximately 4°C).

Before analysis, plant samples were dried (60°C), milled, and passed through a 1 mm sieve as recommended by U.S. EPA (1983). The < 1 mm fraction was analyzed for: TKN by sulfuric acid digestion, NO_3-N by 1 M potassium chloride extraction, Hg by cold vapor atomic absorption, Se by hydride atomic absorption, and all other parameters by nitric/perchloric acid digestion. Digestions or extractions were followed by colorimetric determination of concentration for TKN and NO_3-N; by A.A.S. for Cu and Zn; and by ICP analysis for As, Cd, Cr, Pb, Mo, and Ni. In July 1993, vegetation yield was determined after the samples had been dried at 60°C. More details about laboratory analysis are included in Appendix O.

6.4 Methods and Limitations of Data Analysis - Field Experiment

The analytical methods of data analysis for field data were the same as for laboratory data. Refer to section 3.7 for details.

The data analysis and interpretation of field results was difficult due to the inadequate collection of control data. For example, fewer samples were collected from the control sites (seeded and unseeded) than from the treated sites in the vegetation sampling program. In addition, vegetation samples from the control sites were composited for most parameters whereas discrete samples from the treatment sites were analyzed separately. This approach to sample collection and analysis is not scientific. In future projects, the sampling from the control sites and the treatment sites should be identical to be able to evaluate the effects of different treatments better.

A similar situation existed in the collection of soil fertility data. Instead of collecting composite samples from every treatment site and the control sites at every sampling time, only one discrete sample was collected from the unseeded control site (before biosolids application) and analyzed for soil fertility parameters. This approach to data collection has led to the identification of significant treatment differences in the data analysis for the factor 'time' (different 'before' and 'after' parameter concentrations on individual plots) rather than for the factor 'application rate'. This problem manifested itself in the interpretation of the analytical results for the soil fertility parameters: pH, NO_3-N, NH_3-N, and B. If the control site concentrations had been determined throughout the experiment, significant differences for the different application rates might have been identified. This approach to data collection also led to conflicting results for exchangeable Ca (increased concentrations after biosolids application **and** decreased concentrations with increasing application rates).

7.0 DISCUSSION OF RESULTS - FIELD EXPERIMENT

The following is a discussion of results for the field data that was collected in the Princeton Demonstration Project between October 1992 and October 1993. All laboratory and analytical results for the tailings samples are summarized in tables in Appendices J through N. The appendices include an overview of the analytical results, detailed field data, and a more detailed version of analytical results. The characteristics of the biosolids used in the project are included in Appendix B.

7.1 Field Observations

Growth on the tailings started early in the spring and continued well into the fall even after surrounding vegetation had turned brown. Vegetation was very lush for a non-irrigated site, likely due to a combination of moisture holding capacity of the biosolids, improved nutrient status, and moisture content of the tailings. In the first growing season, the establishment of vegetation on site 3a (179 dt/ha) seemed to be negatively correlated with the thickness of biosolids applied (visual observation).

Field observations include the sighting of deer, cattle, bees, and insects on the treatment sites. Deer started grazing on the treatment sites in July 1993. Deer grazed heavily on the tailings vegetation over the winter 1993/1994. Numerous deer droppings were found on sites 2a, 3a, and 3b in the spring of 1994, but deer droppings were also found on site 2b. In addition, cattle grazed on the sites in the spring of 1994. Grazing did not hamper the vegetation growth in 1994. During the summer of 1993, many bees and other insects were feeding on blossoms on the treatment sites.

7.2 Vegetation in the First Growing Season

The July 1993 vegetation sampling showed that most of the species which were seeded in 1992 grew in 1993. They included fall rye, brome, timothy, crested wheatgrass, fescues, alfalfa, and hairy vetch of which fall rye was visibly the most prominent. The control sites were dominated by weeds and grasses and the treatment sites tended to be dominated by fall rye and grasses. Virtually no legumes were present on the seeded and unseeded control sites, but legumes (primarily alfalfa) contributed 13-15% to the vegetation yield on plots 2a and 2b and 5-7% to the vegetation yield on plots 3a and 3b. In July 1993, the vegetation yield was highest on plot 2b (62 dt/ha) and lowest on the seeded control plot. For details on the July sampling results refer to Appenidx K.

The five discrete vegetation samples collected in September 1993 from tailings sites 2a (77 dt/ha), 2b (62 dt/ha), and 3b (77 dt/ha), and the three discrete samples collected from the control site (0 dt/ha) were statistically compared. For the 179 dt/ha treatment, only yield was compared to the other treatments since only one out of five samples from site 3a yielded enough vegetation for analysis. Results of the data analysis are summarized in Table 18. Refer to Appendix K for details on vegetation results and to section 6.4 for details on limitations of the vegetation data analysis.

The biosolids application to sites 2a (77 dt/ha), 2b (62 dt/ha), and 3b (77 dt/ha) had no significant impact on the foliar concentrations of As, Cd, Pb, Hg, Ni, Se, or Zn. However, the application of biosolids influenced the concentrations of NO_3-N, TKN, Cu, Mo, Cr, and the yield.

The foliar NO_3-N concentration increased after the biosolids application, especially for the 77 dt/ha sites (from 0.003% to 0.04%). The TKN concentration was higher in the vegetation of the 77 dt/ha sites (2.0%) and lower in the vegetation of the 62 dt/ha site (1.2%) in comparison with the control site (1.5%).

The concentration of Cu in the vegetation was lowered substantially after the application of biosolids despite the fact that the available Cu concentration in soil increased slightly after application. This reduction is likely due to a dilution effect caused by good growth and due to less exposure of vegetation to fine Cu dust (less wind erosion and less adherence of Cu onto the surface of vegetation).

The measured Cu concentration in the tailings vegetation was close to the upper normal level in vegetation and was higher than the recommended 4 to 10 mg/kg for cattle consumption (Gould Gizikoff, 1994). However, the measured Cu concentrations in vegetation would not present a hazard to cattle grazing if their diet would not be limited to this feed (BCMAFF, 1991). The Cu concentrations are consistent with previous vegetation research results reported in studies on Princeton mine wastes (Gizikoff, 1990).

TABLE 18. TAILINGS VEGETATION

September 1993 Foliage Quality				Literature Values						
Element		Mean	SD	Normal Conc.			Excess. Conc.			
Arsenic,	mg/kg	7.6	3.3							
Cadmium,	mg/kg	< 0.50					>	3	(3)
Chromium,	mg/kg	AAPPL sig.					>	2	(3)
Copper,	mg/kg	AAPPL sig.		5.0	-	20	>	20	(2,5)
Lead,	mg/kg	5	1.7				>	10	(3)
Mercury,	mg/kg	0.01	0.004						
Molybdenum,	mg/kg	AAPPL sig.		0.1	-	?			(6)
Nickel,	mg/kg	1.15	0.57	0.1	-	1	>	50	(3,4)
NO3-N,	%	AAPPL sig.							
Selenium,	mg/kg	0.19	0.08				>	4	(6)
Total N (TKN),	%	AAPPL sig.		1.5					(1)
Zinc,	mg/kg	30.5	7.8	25.0	-	150	>	400	(2)
Yield,	dt/ha	AAPPL sig.							

1993 Foliage Quality		Application Rate							
Element		0 dt/ha		62 dt/ha		77 dt /ha		179 dt /ha	
Chromium,	mg/kg	3.0	a	1.8	b	1.8	b	not compared	
Copper,	mg/kg	68	a	23	b	21	b	not compared	
Molybdenum,	mg/kg	24	a	5.7	b	4.4	b	not compared	
NO3-N,	%	0.003	b	0.010	ab	0.039	a	not compared	
Total N (TKN),	%	1.5	ab	1.2	b	2.0	a	not compared	
Yield,	dt/ha	0.2	b	4.3	a	5.5	a	0.6	b

The Duncan multiple range test at the 0.05 level of probability was used to determine significantly different means. Means followed by different letters are significantly different.

SD Sample Standard Deviation

(1) Salisbury and Ross, 1991
(2) Mortvedt et al., 1972
(3) CAST, 1976; Melsted, 1973; Univ. of Georgia Coop Ext., 1979
(4) Tisdale et al., 1993
(5) Coker et al., 1982
(6) Walsh and Beaton, 1973

A remarkable trend of lower molybdenum concentration in the vegetation was found, and despite the lowered concentration of Cu in the vegetation, the Cu:Mo ratio increased in the vegetation samples from treatment sites 2a, 2b, and 3b. A higher Cu:Mo ratio is beneficial for ruminants that might graze on the sites. The lower Mo concentration in foliage may be due to the different species composition on the control and treatment sites or due to increased nitrification (lowered pH) and/or increased Fe concentration in soil.

The concentration of chromium was lower in the vegetation after the application of biosolids. The concentration of chromium was lowered below the excess concentration of 2 mg/kg (CAST, 1976; Melsted, 1973; Univ. of Georgia Coop. Ext., 1979).

The yields for the 62 dt/ha and 77 dt/ha treatment sites were much higher after the biosolids application, but the yields for the 179 dt/ha site and the control were comparable. Poor incorporation of the biosolids into the tailings likely contributed to the poor vegetation establishment on site 3a (179 dt/ha site) during the first growing season. Therefore, the southern two thirds of site 3a was rotovated and reseeded in October 1993.

7.3 Soil Fertility (0-15 cm Layer)

In the soil fertility data analysis, NH_4-N and NO_3-N concentrations measured by Norwest Labs and the GVRD Lab were analyzed together to increase statistical accuracy, despite that their laboratory methods were similar but not identical. The NH_4-N and NO_3-N data measured by the GVRD Lab is discussed separately in section 7.4. The Norwest NH_4-N and NO_3-N data is listed in Appendix L and the GVRD data is listed in Appendix M. Limitations of the soil fertility data analysis are discussed in section 6.4.

A factorial analysis with time and application rate as parameters determined that the levels of NH_4-N, NO_3-N, Cu, Bray P-1, Fe, pH, and B were significantly higher after biosolids application. Unaffected by the application of biosolids were the levels of EC, CEC, organic matter, K, Mg, Mn, sulfate, and Zn.

Ammonium, NO_3-N, and Cu concentrations increased after application, although there were significant interaction terms. Bray P-1 and Fe concentrations were dependent on time and application rate, whereas pH and B levels were only dependent on time. Organic matter and CEC were expected to increase after biosolids treatment, and the non-significant result may indicate sampling errors. Sampling errors and recommendations to minimize sampling errors in future projects are discussed in section 7.6. Results of soil fertility analyses are summarized in Table 19 and detailed in Appendix L.

As expected, increased NH_4-N concentrations were measured with increasing application rates. The highest NH_4-N concentration was measured in April 1993. The NH_4-N concentrations in October 1992 (before biosolids application) and in September 1993 were low for all sites, but still higher after treatment than before treatment.

The concentration of NO_3-N was very low before biosolids application, slightly higher 6 months after biosolids application (spring 1993), and much higher one year after application (fall 1993). As expected, the NO_3-N concentration increased with increasing application rates.

The Bray P-1 concentration increased with increasing application rates due to the 1% concentration of total P in biosolids. An approximate comparison of Bray P-1 results with Olsen-P results conducted for April 1993 soil samples showed that both methods tended to lead to similar P fertilizer recommendations. For details refer to Appendix L.

The available iron concentration increased after biosolids application, but remained in the optimum range as before treatment. An increased iron concentration is beneficial since it increases the availability of iron to plants, and since iron oxides can form compounds with metals in biosolids which makes them less available for plant uptake.

TABLE 19. SOIL FERTILITY RESULTS

Parameter		Mean	Std. Dev.	Literature Values Low Conc.	Normal Range	
pH		TIME sig.				
EC,	dS/m	1.5	0.9			
Boron	mg/kg	TIME sig.		< 0.5	0.5	(4)
Bray P-1	mg/kg	TIME and AAPPL sig.		< 7	7 - 20	(1)
Calcium	mg/kg	AAPPL sig.			30 - 300	(2)
CEC,	cmol/kg	7.3	1.3			
Copper	mg/kg	TIME and TIME*AAPPL sig.		< 0.2		(3)
Iron	mg/kg	TIME and AAPPL sig.		< 4.5		(3)
Magnesium,	mg/kg	182	18.1		5 - 50	(2)
Manganese,	mg/kg	4.8	2.2	< 1.0		(3)
NH4-N		TIME and TIME*AAPPL sig.				
NO3-N & NO2-N		TIME and TIME*AAPPL sig.				
%Organic Matter		1.3	1.3			
Potassium,	mg/kg	263	53	< 40	40 - 600	(2)
Sulfate,	mg/kg	224	102	< 5	5	(2)
Zinc,	mg/kg	9.6	8.3	< 0.8		(3)

Parameter		Application Rate 0 dt/ha	62 dt/ha	77 dt/ha	179 dt/ha
Bray P-1,	mg/kg *	3 b	4 b	22 b	83 a
Calcium,	mg/kg *	5016 a	4605 a	3851 b	3376 b
Iron,	mg/kg *	28 b	75 ab	96 a	95 a

* The concentration of the nutrient is also dependent on time.

Parameter		Time Oct. 1992	Apr. 1993	Sept. 1993
pH		8.2 a	8.2 a	7.5 b
Boron,	mg/kg	0.6 a	0.7 a	0.2 b
Bray P-1,	mg/kg **	1.6 b	45 a	51 a
Calcium,	mg/kg **	3411 c	4116 b	4638 a
Iron,	mg/kg **	38 b	63 b	168 a

** The concentration of the nutrient is also dependent on the application rate.

The Duncan multiple range test at the 0.05 level of probability was used to determine significantly different means. Means followed by different letters are significantly different.

(1) Page et al., 1982
(2) Tisdale et al., 1983
(3) Lindsay and Norvell, 1978 (critical levels for corn)
(4) Walsh and Beaton, 1973

NO3-N, NH4-N, and Cu results are detailed in Appendix L.

The pH declined from 8.2 to 7.5 on the treatment sites probably due to increased nitrification. This decrease in pH improves soil fertility as it makes Mo less available and all other micronutrients more available to plants.

After the biosolids treatment, the concentration of B decreased likely due to increased B uptake by legumes or due to local site differences.

The concentration of Ca decreased with the increasing application rates, but was on average higher after biosolids application. The concentration of Ca is very high on the tailings due to the calcareous nature of the ore (see Appendix A).

7.4 Soil Nitrogen and Phosphorus

In this section, N and P data measured by the GVRD Lab are discussed. First, the results of statistical comparisons of concentrations are reviewed which is followed by a discussion of results of soil N balance calculations. **This data set does not include control data.** All soil samples were analyzed on a wet basis for N to minimize volatile losses. Please read section 6.4 before reading the discussion of soil N and P results.

Nitrogen and total P data were statistically compared for the application rates of 62, 77, and 179 dt/ha biosolids and layers 0-15, 15-30, 30-60, 60-90, 90-120, and 120-150 cm. A factorial model with time and application rate as parameters was used in the analysis. Data from every layer was analyzed separately. Table 20 shows the results of the data analyses, and Appendix M includes detailed results. Information in Appendix M was divided into an overview section of statistical results, a N balance section, a field data section, and a detailed analytical results section.

TABLE 20. NITROGEN AND PHOSPHORUS RESULTS (GVRD) - FIELD EXPERIMENT

Depth		TKN (mg/kg)	NO3-N (mg/kg)	NH4-N (mg/kg)	TOTAL P (mg/kg)
0 - 15 cm	Mean	TIME sig.	TIME sig.	TIME	TIME sig.
				AAPPL, and	
				TIME* AAPPL	
				sig.	
15 - 30 cm	Mean	102	11.5	9.7	TIME and
	Std. Dev.	49	19.2	25.5	AAPPL sig.
30 - 60 cm	Mean	54	1.1	0.4	1577
	Std. Dev.	35	1.5	0.3	180
60 - 90 cm	Mean	56	TIME sig.	0.2	1530
	Std. Dev.	11		0.1	217
90 - 120 cm	Mean	55	TIME sig.	0.2	1637
	Std. Dev.	18		0.2	167
120 - 150 cm	Mean	57	TIME,	0.2	1541
	Std. Dev.	14	AAPPL and	0.3	132
			TIME*AAPPL		
			sig.		

Parameter	Depth	Time		
		Oct. 1992	Apr. 1993	Sept. 1993
NO3-N	0 - 15 cm	0.2 b	5.4 b	136 a
	15 - 30 cm	average for all times:		11.5
	30 - 60 cm	average for all times:		1.1
	60 - 90 cm	0.1 b	0.3 ab	0.5 a
	90 - 120 cm	0.1 b	0.3 ab	0.5 a
	120 - 150 cm	all values:		< 3.0
TKN	0 - 15 cm	65 b	861 a	1254 a
Total P	0 - 15 cm	1432 b	1628 ab	1868 a
	15 - 30 cm *	1437 b	1548 ab	1655 a

* **Total P conc. in the15-30 cm profile is also dependent on the application rate.**

15 - 30 cm TOTAL P (mg/kg):

Duncan Group.	AAPPL	N	Mean
a	_179 dt/ha	3	1685
a	_ 77 dt/ha	6	1585
b	_ 62 dt/ha	3	1332

0 - 15 cm NH4-N (mg/kg):

Level of TIME	Level of AAPPL	N	NH4-N Mean	NH4-N SD
_Oct. 1992	_ 62 dt/ha	1	0.1	.
_Oct. 1992	_ 77 dt/ha	2	1.5	1.6
_Oct. 1992	_179 dt/ha	1	0.2	.
_Apr. 1993	_ 62 dt/ha	1	67	.
_Apr. 1993	_ 77 dt/ha	2	215	14.1
_Apr. 1993	_179 dt/ha	1	347	.
_Sep. 1993	_ 62 dt/ha	1	0.3	.
_Sep. 1993	_ 77 dt/ha	2	1.4	1.3
_Sep. 1993	_179 dt/ha	1	5.2	.

Notes:
The Duncan multiple range test at the 0.05 level of probability was used to determine significantly different means. Means followed or preceded by different letters are significantly different.

The concentration of TKN was only significantly different in the 0-15 cm layer for the three application rates. The average concentration of TKN in April and September 1993 was more than 16-fold the concentration in October 1992.

The trends of NH_4-N and NO_3-N concentrations in the 0-15 cm layer measured by the GVRD Lab and Norwest Labs were similar. The combined results were already discussed in section 7.3. The results for NH_4-N and NO_3-N concentrations measured by the GVRD follow below.

The concentration of NH_4-N was only significantly different in the 0-15 cm layer for the three application rates. The concentration was low in October 1992 (pre-application), high in April 1993, and low in September 1993 for all application rates. The April 1993 concentrations were higher for the higher application rates and ranged from 62 to 347 mg/kg for application rates 62 and 179 dt/ha respectively. This result was expected as NH_4-N is the first product in the conversion of organic N to mineral N. The conversion process is temperature dependent and therefore starts anew in spring.

The concentration of NO_3-N was significantly different in the 0-15, 60-90, 90-120, and 120-150 cm layer for the three application rates. The difference was with respect to time. Nitrate in the 120-150 cm layer was also significantly different with respect to application and time*application which means that there was significant interaction between time and application rate. In the 0-15 cm layer, the NO_3-N concentration was low before biosolids application and in the spring following application but was high in September 1993. A high concentration of NO_3-N was expected in the fall due to available organic N for conversion, an established microbial population, reduced nutrient uptake by plants, and generally dry conditions. As expected, the highest NO_3-N concentration in the fall was measured for site 3a with the highest application rate of 179 dt/ha (301 mg/kg). The concentrations of NO_3-N in the 60-90 and 90-120 cm layers were significantly different with respect to time, but the absolute increases were negligible. The average pre-application concentration for the sites was 0.1 mg/kg and the average post-application concentration was 0.3 and 0.5 mg/kg for April and September 1993 respectively. In the 120-150 cm layer, the NO_3-N concentration was highest for September 1993 samples and was highest for the 179 dt/ha application rate (3.0 mg/kg, site 3a). This increase might stem from sample contamination as the tailings are not very permeable.

The total P concentration was higher after biosolids treatment in the 0-15 and 15-30 cm layers. The concentration of total P for the 15-30 cm layer also increased with increasing application rates. Since the total P concentration in biosolids is about 1%, this result is not surprising.

7.4.1 Nitrogen Balance and Summary

An approximate N balance was computed for all sites. The N balance discussion includes the N content measured in vegetation shoots at the end of the first growing season; however, the amount of N in roots or fixed over the growing season was not estimated.The sampling intensity and treatment replication were insufficient to define mass balances between applied TKN, NH_4-N, and NO_3-N, but sufficient to indicate trends that were generally consistent with previous expectations. The data show that nitrification was easily established on all plots as indicated by the nearly complete conversion of NH_4-N to NO_3-N over the first growing season. Complete N balance calculations are included in Appendix M, and Table 21 shows the amount of mineral N measured in the 60-150 cm layer. The discussion of N balances follows in order of increasing biosolids application rates.

TABLE 21. NITROGEN BELOW 60 cm - FIELD EXPERIMENT

Plot	Appl. Rate (dt/ha)	Ratio of (60-150 cm Mineral N) to applied TKN	Oct. '92	Apr. '93	Sept. '93
2b	62	% of TKN applied	0.25%	0.35%	0.38%
2a	77	% of TKN applied	0.16%	0.20%	0.33%
3b	77	% of TKN applied	0.09%	0.28%	0.25%
3a	179	% of TKN applied	0.04%	0.14%	0.39%

Plot	Appl. Rate (dt/ha)	Ratio of (60-150 cm Mineral N) to originally applied Mineral N	Oct. '92	Apr. '93	Sept. '93
2b	62	% of Min. N applied	0.6%	0.8%	0.9%
2a	77	% of Min. N applied	0.3%	0.4%	0.7%
3b	77	% of Min. N applied	0.2%	0.6%	0.5%
3a	179	% of Min. N applied	0.1%	0.3%	0.8%

Application Rate 62 dt/ha - Plot 2b

The spring 1993 composite soil data account for only 34% of the estimated applied TKN and the fall 1993 data was only marginally better (55%), probably due to problems in sample collection. Soil TKN concentration only increased in the 0-30 cm layer.

During the first growing season, soil mineral N appears to have been taken up or lost to either volatilization or denitrification since there was no residual N in the fall of 1993 and NO_3-N leaching below 60 cm was negligible (< 6 kg/ha). The results for the discrete soil samples were much lower than for the composite soil samples except for mineral N in the 60-150 cm layer (< 16 kg/ha).

At the end of the first growing season, N in the shoots accounted for 3% (52 kg/ha) of the applied N.

Application Rate 77 dt/ha - Plot 2a

The spring 1993 TKN concentrations in composite soil samples accounted for only 49% of the applied TKN indicating sampling difficulties. However, the fall 1993 data accounted for 84% of the applied TKN. The TKN results were variable but as expected, TKN did not appear to migrate downwards.

The spring 1993 mineral N data accounted for 41% of the applied mineral N indicating high initial volatile losses. During the first growing season, about 270 kg N/ha was lost which corresponds to the high yield measured on plot 2a (5100 kg/ha). At the end of the first growing season, N in the shoots accounted for approximately 4% of the applied N. Virtually no NO_3-N leaching below 60 cm occurred (< 9 kg/ha). The average results for discrete soil samples were much lower than for composite soil samples and do not appear to be representative.

Application Rate 77 dt/ha - Plot 3b

The 1993 composite soil data for plot 3b shows very good recovery of the applied TKN (75% in spring and 85% in fall) and poor recovery of mineral N (33% in spring and 35% in fall). As was the case for all of the other plots, spring 1993 mineral N was predominantly NH_4-N indicating that no nitrification occurred over the winter and early spring. The fall 1993 data shows again the complete nitrification of the NH_4-N present in the spring, but fails to show any significant N losses over the growing season suggesting that the rate of mineralization and plant uptake where comparable. Nitrate leaching was not evident over the first growing season.

The discrete soil sampling data for plot 3b showed very good agreement with the composite soil samples for TKN and NH_4-N, but NO_3-N concentrations were very high in the spring of 1993 (799 kg/ha in 0-15 cm layer). This high value for NO_3-N in the early spring contradicts the results from all other plots and is not reflected in the fall 1993 data and may have resulted from sample contamination.

At the end of the first growing season, N in the shoots accounted for approximately 5% of the applied N.

Application Rate 179 dt/ha - Plot 3a

The TKN recovery in spring 1993 soil samples was very poor (22%) but somewhat better in the fall (43%) again probably due to sampling difficulties. Soil mineral N recoveries were similarly low (17%) but may reflect significant volatile losses due to the large quantity of biosolids exposed on the soil surface. The high NH_4-N concentration in the spring of 1993 was almost completely nitrified over the growing season.

Slightly elevated NO_3-N levels at the 120-150 cm depth appear to be due to a sampling error (biosolids falling into the hole) as there is no indication that moisture penetrated from the surface to that depth in 1993.

The discrete soil samples for plot 3a were in much closer agreement with the composite soil samples than for the other plots. Discrete mineral N levels were approximately 100 kg N/ha less on average than composite levels.

At the end of the first growing season, N in the shoots of the one sample collected from site 3a accounted for 1% of the applied N.

7.5 Total Metals in Soil

The metal concentrations in tailings samples collected in October 1992, and April and September 1993 were statistically compared for application rates 77 dt/ha (site 3b only) and 179 dt/ha (site 3a). The data analysis was accomplished with the main effect model with parameters 'time' and 'application rate'. Results of the data analysis are summarized in Table 22 and are detailed in Appendix N. Note that in the data analyses, concentrations below the detection limit were assumed to be half the concentration of the detection limit.

In the data analysis for application rates 77 and 179 dt/ha, statistically significant differences were only identified for the metals Al, As, and Hg. The concentration of Al was significantly different in the 90-120 and 120-150 cm layers. However, since Al is abundant in soils and the Al concentrations in the different tailings plots varied between 16200 and 40000 mg/kg before treatment, the difference in Al concentrations is likely due to a site difference rather than a treatment difference. Since As does not leach readily, the difference in As concentrations in the 30-60 and 90-120 cm layers is also probably due to a site difference rather than a treatment difference. Arsenic concentrations tended to be highest in April 1993, but were close to the detection limit (7 mg/kg). All measured As concentration were well below the Level of Quantification (21 mg/kg). The Hg concentration went up in the 0-15 cm layer from below the detection limit (0.2 mg/kg) to 0.2 to 0.4 mg/kg after biosolids application. Since the Level of Quantification for Hg is 0.6 mg/kg, changes in Hg concentrations are only subtle.

All soil metals were below the CCME criteria (1991) for agricultural or residential soils except for Cu.

7.6 Problems and Errors in Sample Collection of Field Samples

The Princeton Biosolids Demonstration Project is believed to be the first of its kind in British Columbia and was very successful in achieving revegetation. The following paragraphs point out some of the problems that were encountered during soil and vegetation sampling and include suggestions to minimize problems and errors in future projects.

TABLE 22. TOTAL METALS IN SOIL - FIELD EXPERIMENT

Metal		Selenium (mg/kg)	Mercury (mg/kg)	Arsenic (mg/kg)	Aluminum (mg/kg)	Cadmium (mg/kg)	Chromium (mg/kg)
Depth							
0 - 15 cm	Mean	0.5	TIME	< 5.0	21633	< 0.5	37.8
	Std. Dev.	0.1	sig.		1297		2.2
15 - 30 cm	Mean	0.5	< 0.2	< 5.0	28450	< 0.5	48.7
	Std. Dev.	0.1			1911		3.3
30 - 60 cm	Mean	0.4	< 0.2	TIME	33333	0.5	52.3
	Std. Dev.	0.1		sig.	3747	0.04	1.6
60 - 90 cm	Mean	0.4	< 0.2	3.8	32017	0.6	53.8
	Std. Dev.	0.1		2.7	2763	0.3	4.4
90 - 120 cm	Mean	0.3	< 0.2	TIME	AAPPL	0.5	55.7
	Std. Dev.	0.07		sig.	sig.	0.3	2.2
120 - 150 cm	Mean	0.32	< 0.2	2.9	AAPPL	0.35	54.2
	Std. Dev.	0.04		0.61	sig.	0.04	1.08
Normal Range: *		0.1 - 2	0.02 - 0.2	1 - 50	10000 - 200000	0.01 - 7	5 - 1000
Typical Concentration: *		0.5	0.05	5	50000	0.06	20
CCME: **		2	0.8	20		3	250

0 - 15 cm Mercury (mg/kg):

Duncan Grouping	Mean	N	TIME
a	0.4	2	_Sep. 1993
b	0.1	2	_Oct. 1992
b	0.1	2	_Apr. 1993

30 - 60 cm Arsenic (mg/kg):

Duncan Grouping	Mean	N	TIME
a	5.0	2	_Apr. 1993
b	3.0	2	_Oct. 1992
b	2.5	2	_Sep. 1993

Notes:
The main effects of AAPPL and TIME (i.e. no interactions) were examined in the analysis.
The Duncan multiple range test at the 0.05 level of probability was used to determine significantly different means. Means preceded by different letters are significantly different.
'Std. Dev. ' refers to the sample standard deviation.

- Cobalt, nickel, and zinc concentrations remained relatively unchanged.
- Lead concentration was close to the Limit of Detection and tended to be lower after treatment.
- Molybdenum concentration was below the Limit of Detection.

* Bohn et al., 1985

** lowest of the remediation limits for agricultural or residential soils set by the Canadian Council of Ministers of the Environment (1991)

Like all data, the Princeton field data had associated systematic and random errors. Systematic errors can be traced to a cause while random errors result from many different causes and their effects can be minimized by collecting and averaging more comparable data.

The main error in the Princeton project is believed to be a systematic error that resulted from the collection of soil samples in the field. The collection of representative samples from the treated plots was very challenging. Finding less total N on the sites than was applied and not measuring a proportional increase in organic matter content and CEC with increasing application rates of biosolids indicates that representative samples were not always collected.

Soil Samples

Contamination of soil samples might occur during their collection, handling, transport, or analysis in the laboratory. Under dry weather conditions, contamination problems at the time of collection can usually be kept to a minimum, but if it is raining or if the soil surface is wet, contamination is harder to avoid since the biosolids and the tailings tend to get slimy. Contamination during transport to the laboratory could have happened if a sample bag was not properly closed or opened up under the weight of other bags.

Composite Soil Samples

When biosolids are applied very evenly to a treatment site, the collection of representative composite samples is easy as deviations from the mean are small. Operational scale field application of biosolids with manure spreaders worked well on the tailings when considering soil fertility status and vegetation establishment. The only problem with the manure application was the collection of representative soil samples after application since manure spreaders left biosolids in chunks of 2 to 10 cm in diameter on the ground that were not uniformly distributed. The disking operation after application broke up and incorporated the biosolids fairly well for the lower application rates (62 and 77 dt/ha) but not well for the highest application rate (179 dt/ha).

In addition, the sampling probe had a tendency to part the biosolids on the soil surface rather than core them, leading to lower nutrient and organic matter results than were expected. In hindsight, although the size of the sampling probe was probably adequate for soil samples for layers below the zone of incorporation, it was not large enough for the 0-15 cm layer. A subsample volume of 10 cm in diameter and 15 cm in depth would have been able to sample typical soil surface conditions on the tailings. Ten subsamples per sample would probably have been adequate.

To avoid sample contamination, the soil probe was cleaned after the collection of every subsample and the soil probe was kept off the soil surface when emptying soil cores into sample bags. In addition, the exposed part of soil cores was discarded. Sample contamination from the surrounding soil could be overcome by collecting samples into small hollow plastic tubes that fit into the sampling probe. An appropriate plastic tube has still to be investigated since some subsurface layers of the tailings are hard and might break the plastic tube inside the soil probe. Once collected, the plastic tubes can be sealed at the bottom and top in the field and the bottom and top sections can be wasted in a laboratory to avoid contamination.

Another source of contamination is from biosolids that fell into a sampling hole from the soil surface. To avoid this problem, biosolids were cleared away around sampling holes (15-20 cm in diameter) and the top 2 cm of every soil core was discarded.

Discrete Soil Samples

Discrete soil samples were collected from the edges of freshly dug soil pits with trowels. While collecting a soil sample, care was taken to collect a vertical layer of the same diameter throughout. Contamination errors might have occurred through biosolids that fell into the pit.

In hindsight, it would probably have been better to collect two to three extra composite samples from every treatment site rather than discrete samples since site variations were great and many more discrete samples (at a high cost per sample) would be necessary to determine the site variation well. In comparison, a few composite samples per treatment could have established a treatment mean and provided an estimate of variance about that mean with reasonable accuracy and at a reasonable price. A good estimate of the treatment means would have led to a better base for comparative study of different treatments.

Vegetation Samples

The fertilization benefit of biosolids application on plant health was difficult to assess due to the lateness of the sampling season affecting the maturity of plants. In addition, the vegetation samples were only analyzed as a whole and not separated according to species although the time of sampling and the maturity of plants make an extreme difference in nutrient levels between species.

Contamination errors in vegetation samples might have resulted from tailings and biosolids adhering to vegetation samples since they were not washed before analysis.

In future monitoring efforts, vegetation samples should be analyzed by species and sampling should be conducted prior to the flower stage (preferably late June) to determine the effect of biosolids application on macronutrient and metal contents and/or during the grazing season (spring/early summer) to determine forage suitability for animal consumption (cattle and deer).

Other Errors

Other errors that were associated with data collected during the Princeton Demonstration Project include inadequate collection of crucial data or the collection of data that were not comparable. For example, the analysis of characteristics of biosolids added to the tailings did not include the analysis of TKN in land-dried biosolids. Therefore, an approximate TKN concentration had to be estimated from historical data. Records on the application of different types of biosolids to site 2b are not complete which impeded the interpretation of results and calculation of mass balances.

Ideally, all sample data that are to be compared have to be collected, composited, and analyzed in the same fashion. In the field project, control and treatment samples were sometimes composited differently making the results less comparable and the data interpretation difficult.

Laboratory methods used were not always as recommended for high pH soils. For example, available P should have been determined with the Olsen-P method (Page et al., 1982) and organic matter should have been measured with an organic C (TC-IC) rather than a total C method (Page et al., 1982).

Actual concentrations of exchangeable Ca^{2+} might have been different than were measured due to the presence of free Ca^{2+} (Page et al., 1982).

8.0 SUMMARY OF MAIN RESULTS - FIELD EXPERIMENT

The demonstration project was very successful. Nitrification was easily established on all plots as indicated by the nearly complete conversion of NH_4-N to NO_3-N over the first growing season. Vegetation was established within one growing season on all sites. The established vegetation was more vigorous than on the control sites and the wind erosion from the demonstration sites has stopped, and all site improvements were accomplished without irrigation. Over the last two growing seasons, there has been vigorous growth, especially of alfalfa, a N fixing legume. Compared to the sparse natural revegetation over the past 40 years, the growth rate is remarkable.

Tailings Soil Fertility

NH_4-N, NO_3-N, Fe, and the organic matter content tended to increase with increasing application rates.

The concentration of NH_4-N tended to be high in the early spring and low in the fall, whereas the NO_3-N concentration tended to be low in the early spring and high in the fall, indicating high nitrifier activity through the growing season.

Nitrate leaching from plots 2a (77 dt/ha), 2b (62 dt/ha), 3a (179 dt/ha), and 3b (77 dt/ha) was negligible in the first growing season. For details, refer to Table 21 or Appendix M (Nitrogen Balance Section).

Plant available Cu in the tailings tended to increase following biosolids application.

Tailings Vegetation

In 1993, fall rye, brome, timothy, crested wheatgrass, fescues, alfalfa, and hairy vetch grew of which fall rye was visibly the most prominent. The control sites were dominated by weeds and grasses and the treatment sites tended to be dominated by fall rye and grasses. Virtually no legumes were present on the seeded and unseeded control sites, but legumes (primarily alfalfa) established on the treatment sites.

The treatment of Princeton tailings with 77 dt/ha stored dewatered biosolids led to improved vegetation quality and yield for all parameters tested.

Levels of Cu and Mo decreased in foliage whereas other metals remained essentially unchanged. A notable trend of a higher Cu:Mo ratio was determined for vegetation collected from sites of 2a, 2b, and 3b. The trend toward lower Mo levels in foliage is possibly a result of the different species composition on the control and treatment sites, increased nitrification resulting in lowered soil pH and reduced Mo availability to plants, or increased Fe concentration in soil.

Cattle and deer grazing in 1993 has not hampered the vegetation growth.

In future vegetation monitoring, vegetation should be sampled by species and treatment site, and preferably prior to the flower stage (late June) to allow for a better interpretation of results.

Tailings - Total Metals

The Hg concentration increased with increasing application rates, but the increases were very slight and below the Level of Quantification.

All soil metals were below the CCME criteria (1991) for agricultural or residential use except for Cu.

9.0 CONCLUSION

The revegetation of copper mine tailings in Princeton B.C. (pH 8.0) with biosolids and seeds was very successful. Vegetation established without irrigation within one growing season on all sites, and was more vigorous on the treated sites than on the control site. Nitrification was easily established on all plots as indicated by the nearly complete conversion of NH_4-N to NO_3-N over the first growing season. Positive environmental effects after biosolids application were major: accelerated reclamation, reduced wind erosion, improved vegetation quality, increased yield, improved soil fertility, and good establishment of alfalfa (*Medicago sativa*) whereas the negative effect was minor: increased but not quantifiable Hg concentrations in the 0-15 cm layer. The laboratory experiments showed that the growth of salt sensitive vegetation may be reduced when applying 300 dt/ha freshly dewatered anaerobically digested biosolids to the Princeton tailings (soil EC ~ 4dS/m).

The laboratory leaching experiments demonstrated that although NO_3-N concentrations were relatively high in the 0-15 cm layer (up to 3000 kg/ha for the 300 dt/ha application rate), NO_3-N in leachate was less than 2.4 mg/L for most columns; however, the experiments also showed that NO_3-N leaching can be substantial when biosolids are applied to tailings which are prone to water erosion as biosolids can be swept with the tailings downstream. The potential of NO_3-N contamination of groundwater after further applications of biosolids to the Princeton tailings (at similar rates) is very low due to the low permeability of the tailings, the low annual precipitation, the flat terrain, and the increased evapotranspiration after good vegetation establishment.

The mineralization rates measured in the laboratory experiments ranged from 17 to 31% under wetter conditions and from 29 to 43% under dryer conditions, and were higher than the EPA guideline level of 20% (U.S. EPA, 1983). Besides measurement errors that could have overestimated the N losses leading to a high estimate of the mineralization rate, the high mineralization rate is likely due to the good mixing of biosolids with the tailings, and due to close to optimum conditions for mineralization and nitrification in soil (pH > 7.5; temperature ~ 17°C). Furthermore, EPA guidelines were based on a number of projects, many of which were acid generating spoils in which the mineralization and nitrification rates are lower even after the pH was raised to 6.5 before the application of biosolids.

Nitrogen losses in the laboratory and field experiments were high, especially for the highest application rates, although the actual N losses were probably smaller. This could have been proven by better sampling and/or laboratory procedures. Nitrogen losses were about 30% for the 300 dt/ha application rate in the laboratory and in the 50% range for the 179 dt/ha application rate in the field. The author believes that the silty nature of the tailings contributed to the slow NO_3-N leaching which in turn led to an accumulation of NO_3-N in the upper layer from which N was lost through denitrification after temporary flooding of the soil (storm events). In addition, the high pH likely contributed to volatilization losses.

As expected in calcareous tailings, metals did not leach in the field or the laboratory experiments. Only the Hg levels in the 0-15 cm layer and for the 300 dt/ha application rate were above the maximum recommended metal concentration in soil in B.C. (B.C. MOE, 1983).

In future projects, the results of the field project and laboratory experiments can be applied to all of the Princeton tailings and likely to other copper mine tailings in the semi-arid interior of B.C. Furthermore, the successful reclamation of the Princeton tailings with biosolids suggests the possibility of waste rock reclamation with a mixture of tailings and biosolids in cases where not enough overburden is available for reclamation. Another project for further research may be the study of the environmental effects after the application of biosolids and seeds to acidic mine wastes in B.C. (after raising the spoil pH to 6.5) , something extensively practiced in Pennsylvania (Sopper, 1993).

10.0 RECOMMENDATIONS

In the author's opinion, the mineralization rate should be studied in more detail and under more controlled conditions. To study the mineralization rate, one experimental design could include the setup of 100 short columns (20 cm in height) which are all exposed to the same environmental conditions. The contents of five of the columns could be analyzed weekly for TKN, NO_3-N, and NH_4-N to expose the mineralization behaviour of organic N in biosolids when mixed with soil or tailings (exponential, logarithmic, quadratic, or linear behaviour).

Recommendations - Field Experiment

- Conduct of same procedures of sample collection and analysis for the control and treatment sites.

- Collection of larger soil subsamples from the zone of biosolids incorporation to obtain representative samples.

- Monitoring of vegetation samples by species and treatment.

- Monitoring of vegetation for macronutrient and metal content prior to the flower stage and/or during the grazing season.

- Higher replication of the application rates (at least treatment duplication).

- Establishment of a database for background and control site concentrations.

- Establishment of a database for average concentrations of all major elements in biosolids and where and when they were applied.

Recommendations - Laboratory Experiments

- Analysis of particulates in leachate for NO_3-N and TKN to determine if or how much of the NO_3-N and TKN in leachate may be attributed to sample contamination with biosolids.

- Increased sampling intensity and a switch to larger sample sizes (2-4 g) for the TKN analysis to improve the accuracy of Total Nitrogen results.

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APPENDIX A

Environmental Data for Princeton, B.C.

PRINCETON DEMONSTRATION PROJECT - RESEARCH SITE INFORMATION

Owner of Tailings:	Township of Princeton, B.C.
Location:	
Lat.:	49° 27'30" N
Long.:	120° 29' 0" W
Distance from Princeton (SSE):	4 km
Distance from Similkameen River:	275 m
Elevation of Research Sites:	667 m
Height above Shores of Similkameen River:	43 m
Depth to Native Till:	17 m
Slope:	< 0.25 %

Average Climatic Data for the Princeton Airport (Canadian Climatic Normals (Vol. 6); Dec. 1, 1971 - Nov. 30, 1991)

The climate is semi-arid with wide ranging variations.

Temperature:

The mean temperature is 5oC with extremes of -41oC to +38oC.

Frost free days (144-year average):	104
Earliest Last Frost on Record:	May 22
Latest Last Frost on Record:	Jul. 5
Earliest First Frost:	Aug. 1
Latest First Frost:	Oct. 7

Precipitation:

Mean yearly PPT:	354 mm,	s = 188 mm
Mean PPT between May 1 and Sept.30:	138 mm	

Evapotranspiration:

Mean ET between May 15 and Sept.15:	752 mm	(110 % Hargreaves)

ESTIMATE OF EVAPOTRANSPIRATION WITH THE HARGREAVES EQUATION

A comparative study of field lysimeter measurements at various locations with estimates of evapotranspiration models determined that the Hargreaves model produced daily estimates of reference ET that were equal to the average lysimeter measurement, but that it underestimated evapotranspiration by 10 percent in arid locations (ASCE, 1990). However, since the Princeton tailings are silty, the capillary rise may not proceed in the same way as in agricultural soils, and therefore, evapotranspiration estimates are only approximate.

Month:	Day in Year	Declination: (rad)	Relative Distanc (sun to earth)	Sunset Hour Angle: (rad)	Extrater. Radiation RA MJ/(m^2*d)	Mean Monthly Tmax: (°C)	Mean Monthly Tmin: (°C)	TD: (°C)	Average Monthly Temp. (°C)	Lambda ET0: (MJ/(m^2*d))	ET0: (mm/d)	110% ET (mm/d)	110% ETO per month (mm/month)
Jan 15	15	-0.3712	1.0319	1.0987	9.19	-2.4	-10.6	8.2	-6.5	0.68	0.3	0.3	9.5
Feb 15	46	-0.2320	1.0232	1.2913	14.72	2.0	-7.7	9.7	-2.8	1.58	0.6	0.7	19.9
Mar 15	74	-0.0492	1.0097	1.5132	22.46	8.5	-3.8	12.3	2.3	3.64	1.5	1.6	50.7
Apr 15	105	0.1643	0.9923	1.7657	31.66	14.1	-0.9	15.0	6.6	6.88	2.8	3.1	92.7
May 15	135	0.3280	0.9774	1.9796	38.55	18.2	3.2	15.0	10.7	9.79	4.0	4.4	136.2
Jun 15	166	0.4069	0.9683	2.0984	41.74	22.3	6.8	15.5	14.6	12.25	5.0	5.5	165.0
Jul. 15	196	0.3756	0.9679	2.0494	40.31	26.1	9.0	17.1	17.6	13.57	5.5	6.1	188.9
Aug 15	227	0.2406	0.9762	1.8614	34.57	26.0	9.0	17.0	17.5	11.57	4.7	5.2	161.0
Sep 15	258	0.0387	0.9912	1.6160	25.95	21.3	4.5	16.8	12.9	7.51	3.1	3.4	101.2
Oct. 15	288	-0.1675	1.0080	1.3719	17.23	13.7	-0.3	14.0	6.7	3.63	1.5	1.6	50.6
Nov 15	319	-0.3342	1.0232	1.1532	10.55	3.3	-4.6	7.9	-0.6	1.17	0.5	0.5	15.8
Dec 15	350	-0.4079	1.0319	1.0416	7.81	-2.8	-9.4	6.6	-6.2	0.54	0.2	0.2	7.5

Notes: The estimated evapotranspiration between Nov. 15 and Apr. 15 is 196 mm.
The estimated evapotranspiration between May 15 and Oct. 15 is 803 mm.
The estimated evapotranspiration between May 15 and Sept. 15 is 752 mm.
The latitude of the station is 49 degrees and 26 minutes.

The Hargreaves Equation is defined as:

lambda ET0 = $0.0023 \cdot RA \cdot TD^{0.5} \cdot (T+17.8)$ (MJ/(m^2*d))

where

lambda ET0	evapotranspiration	
lambda	latent heat of vaporization	(J/kg)
ET0	evapotranspiration	(mm/d)
RA	extraterristrial radiation	(MJ/(m^2*d))
TD	mean monthly maximum temperature - mean monthly minimum temperature	(°C)
T	mean monthly temperature	(°C)

CHARACTERISTICS OF COPPER ORES FROM COPPER MOUNTAIN (B.C. Minfile #092HSE001)

Dominant host rock:	Volcanic				
Commodities:	Copper	Gold	Silver		
Minerals:	Chalcopyrite	Pyrite	Bornite	Chalcocite	
Alteration:	Biotite	Albite	Epidote	K-Feldspar	Scapolite
Deposit Classification:	Porphyry	Hydrothermal			
Isotopic Age:	193+-7 Ma				
Mineralization Age:	Lower Jurassic				
Lithology:	Andesitic Basaltic Tuff Breccia Andesitic Basaltic Tuff Andesitic Basaltic Flow Andesitic Basaltic Agglomerate Diorite Diorite Porphyry Dyke Felsite Dyke Pegmatite Vein				

APPENDIX B

Biosolids Characteristics & Seed Mix

PRINCETON DEMONSTRATION PROJECT - BIOSOLIDS CHARACTERISTICS

Element	Field Experiment	Field Experiment	Laboratory Experiment	Laboratory Experiment	B.C. Draft Guidelines for the Disposal of Domestic Sludge (1983)	
	Annacis Land-dried Biosolids	Annacis Stored Dewatered Biosolids	Annacis Freshly Dewatered Biosolids	Annacis Freshly Dewatered Biosolids	Classification	
	Applied to northern 1/3 of P2b	Applied to P2a, P3a, P3b, & southern 2/3 of P2b	Run 1 *	Run 2 **	Agricultural Low Grade	Retail High Grade
	Oct-92	Oct-92	Mar. 93	Aug. 93		
% Moisture	30.7	75	74	72	-	< 70
pH (1:2)			8	8	-	-
Loss on Ignition (@ 450 oC)			71	74	-	-
Total Kjeldahl N (mg/kg)	~ 11000	33785	35728	41890	-	-
Nitrate/Nitrite-N (mg/kg)	101	5	2	3	-	-
Ammonium-N (mg/kg) - extracted	241	12072	3728	4462	-	-
Ammonium-N (mg/kg) - distilled	266	16733	3636	5212	-	-
Total Phosphorus (mg/kg)			10484	13921	-	-
Arsenic (mg/kg)	< 12	< 17	< 9	< 17	75	75
Cadmium (mg/kg)	1	5	4	3	25	5-20
Chromium (mg/kg)	40	50	60	58	-	-
Cobalt (mg/kg)	5	4	4	< 3	150	150
Copper (mg/kg)	219	1050	820	904	-	-
Lead (mg/kg)	88	190	156	139	1000	500
Mercury (mg/kg)	2.9	6.7	5.4	5.7	10	5
Molybdenum (mg/kg)	< 4	7	7	8	20	20
Nickel (mg/kg)	31	37	28	24	200	180
Selenium (mg/kg)	1	6	7	5	14	14
Zinc (mg/kg)	193	915	621	671	2500	1850

Notes:

* The average concentrations of 5 samples.

** The average concentrations of 4 samples.

All samples were analyzed by the GVRD Lab using extraction and digestion methods described in Appendix O.

The concentrations are on a dry weight basis.

SEED MIX USED IN THE PRINCETON DEMONSTRATION PROJECT

Reclamation Mix:			Species Characteristics *:
20%	BOREAL Creeping Red Fescue	Festuca rubra	well developed root system, deep rooting
15%	Hard Fescue	Festuca ovina var. duriuscula (L.) Koch	31 cm Mean Annual Precipitation (MAP), pH ~ 7, cold-hardy, any elevation, slow developing
10%	CARLTON Bromegrass	Bromus inermis	fast-developing, long-lived perennial, cold-hardy, high nitrogen requirement, likes well-drained soils
10%	STREAMBANK Wheatgrass	Agropyron riparium Scribn. & Smith	drought tolerant, quick germinating, cool-season
10%	FAIRWAY Crested Wheatgrass	Agropyron cristatum (L.) Gaertn.	20-35 cm MAP, cold-hardy, drought tolerant, high elevation, slow-developing
5%	Canada Bluegrass	Poa compressa L.	perennial, summer active, pH 5.5-6.5, low fertility soils
5%	ALMA Timothy	Phleum pratense L.	51 cm MAP, pH sligthly acid, cold-hardy, high elevation
10%	RANGELANDER Alfalfa	Medicago sativa L.	41 cm MAP, pH > 6.5, cold-hardy, perennial
5%	White Clover	Trifolium repens L.	45 cm MAP, pH 6-7, perennial
5%	SC Red Clover	Trifolium pratense L.	50 cm MAP, pH 5.5-6.5, cold-hardy, perennial
5%	CICER Milkvetch	Astragalus cicer L.	35 cm MAP, drought tolerant, high elevation, perennial, slow-developing, low percentage germination

Nurse Crop Seed Mix:

67%	Fall Rye	Secale cereale
33%	Hairy Vetch	Vicia villosa

Notes:

* Land Management Report Number 4, B.C. Min. of Forests (1980); Tisdale et al. (1993)

The reclamation seed mix and the nurse crop seed mix were seeded at 65 and 30 kg/ha respectively. All legumes were inoculated with the appropriate Rhizobium inoculum.

APPENDIX C

Leaching Experiments - Water Regimes
& Related Princeton Precipitation Data

Leaching Experiments - Quantity of Leachate Collected

Leaching Experiments - Days with Particulates in the Leachate

Leaching Experiments - Standing Water on Top of Test Columns

Leaching Experiments - Temperature Regimes

WATER REGIME FOR THE LEACHING EXPERIMENTS

Week	Day in Leaching Run	Leaching Run 1: Distilled Water (DI) added to Columns (mm)	Leaching Run 1: DI added to Columns/Week (mm)	Leaching Run 2 and Pot Trial: DI added to Columns (mm)	Leaching Run 2 and Pot Trial: DI added to Columns/Week (mm)
1	1	33		33	
	2	31	63	31	64
2	8	26		26	
	9	6	32	6	32
3	15	13		13	
	16	4	17	4	17
4	22	13			
	23	4	17		
5	29	13			
	30	4	17		
6	36	13			
	37	4	17		
7	43				
	44				
8	50			3	
	51			9	12
9	57	3		5	
	58	5	8	5	10
10	64	3			
	65	5	8		
11	71				
	72				
12	78			5	
	79			9	14
13	85			5	
	86			9	14
Total Water added (mm):		180		163	

Summary of Single Set Maximum Frequency Analyses of Exceedence for 20 Years of Rainfall Data recorded at the Princeton Airport , B.C. (Dec. 1, 1971 to Nov. 30, 1991) *

Return Period in years:	1-Day Maximum Precipitation (mm)	2-Day Maximum Precipitation (mm)	3-Day Maximum Precipitation (mm)	5-Day Maximum Precipitation (mm)
1.01	8	9	14	18
2	23	31	35	39
5	32	44	47	51
10	38	53	56	59
20	44	61	64	67
25	45	64	66	70
50	51	72	74	77
100	57	80	82	85

* assuming Gumbel distribution

WATEREG.XLS

Summary of Frequency Analyses for Rainfall Data recorded at the Princeton Airport between Dec. 1, 1971 and Nov. 30, 1992

Return Period	Yearly Maximum Precipitation (mm)	Seasonal Maximum Precipitation (mm)	
		(Nov. 1 -> Apr. 30)	(Feb.. 1 -> Apr. 30)
	12 months	6 months	3 months
1.01	200	65	3
2	343	179	58
5	429	247	92
10	486	293	114
20	540	336	135
25	557	350	142
50	611	392	162
100	664	434	183

* assuming Gumbel distribution

Summary of Frequency Analyses for Rainfall Data recorded at the Princeton Airport between Dec. 1, 1971 and Nov. 30, 1992

Average Contribution of Storms to Yearly Precipitation in 20-year Period: (Dec. 1, 1971 -> Nov. 30, 1991)		Average Contribution of Storms to Seasonal Precipitation in Seasons:				
			(Nov. 1 -> Jan. 31)	(Feb.. 1 -> Apr. 30)	(May 1 -> Jul. 31)	(Aug. 1 -> Oct. 31)
1-Day Storm	16.9%	**1-Day Storm**	12.2%	21.3%	24.6%	21.5%
2-Day Storm	23.1%	**2-Day Storm**	20.7%	26.7%	28.2%	32.2%
3-Day Storm	20.5%	**3-Day Storm**	18.4%	18.3%	21.5%	22.8%
4-Day Storm	16.1%	**4-Day or longer Storm**	48.7%	33.8%	25.7%	24.1%
5-Day Storm	11.2%					
6-Day or longer Storm	12.2%					
20-year Avg. Precipitation (mm)	354		133	63	87	68
Sample Std. Deviation (mm)	188		42	31	41	33

LEACHING RUN 1 - QUANTITY OF LEACHATE COLLECTED

Col.	Tailings from Site	Col. Length	Applic. Rate	Total Leachate Water collected	Weekly quantity of leachate collected from 5.5 " (13.97 cm) columns (in mm). Week 1 (Days 1 -> 7) Mar. 15 -> 21	Week 2 (Days 8 -> 14) Mar. 22 -> 28	Week 3 (Days 15 -> 21) Mar. 29 -> Apr. 4	Week 4 (Days 22 -> 28) Apr. 5 -> 11	Week 5 (Days 29 -> 35) Apr. 12 -> 18	Week 6-9 (Days 36 -> 56) Apr. 19 -> May 9	Week 9 (Days 57 -> 63) May 10 -> 16	Week 10 (Days 64 -> 70) May 17 -> 25
		(cm)	(dt/ha)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
C1	1	0-90	0	112	10	15	13	14	13	38	6	4
C2	1	0-90	30	131	12	15	14	13	13	37	13	14
C3	1	0-90	100	150	24	25	23	21	21	29	4	4
C4	1	0-90	300	146	30	28	23	18	16	20	5	6
C5	1	0-90	300	130	19	21	18	16	16	29	6	6
C6	1	0-45	0	118	60	8	12	13	13	13	0	0
C7	1	0-45	30	137	57	30	12	13	13	13	0	0
C8	1	0-45	100	142	64	29	12	12	12	12	0	0
C9	1	0-45	300	127	35	27	23	16	16	11	0	0
C10	1	0-60	0	145	50	32	16	16	14	13	3	2
C11	1	0-60	30	143	56	33	14	15	13	12	0	0
C12	1	0-60	100	144	50	33	18	14	14	14	0	0
C13	1	0-60	300	125	36	27	15	13	15	15	2	2
C-A	2	0-90	0	139	20	22	21	19	19	27	5	4
C-B	2	0-90	30	148	17	20	18	17	16	44	8	6
C-C	2	0-90	100	142	16	19	16	16	15	41	11	8
C-D	2	0-90	300	129	15	19	15	13	14	34	10	10
C-E	2	0-90	300	142	25	23	18	16	17	29	8	6
C-F	2	0-45	0	148	60	29	14	14	14	14	1	2
C-G	2	0-45	30	144	58	30	14	14	14	13	0	1
C-H	2	0-45	100	145	59	29	14	14	14	14	1	1
C-I	2	0-45	300	158	51	31	17	14	16	19	4	6
C-J	2	0-60	0	144	61	29	13	13	14	13	0	2
C-K	2	0-60	30	139	60	27	12	13	13	13	0	0
C-L	2	0-60	100	147	62	29	14	13	13	16	0	0
C-M	2	0-60	300	158	57	30	16	15	16	15	4	6

All samples were analyzed in the BIOE Laboratory.

LEACHING RUN 1 - QUANTITY OF LEACHATE COLLECTED

Col.	Tailings from Site	Col. Length	Applic. Rate	Total Leachate Water collected	Weekly quantity of leachate collected from 5.5 " (13.97 cm) columns. Week 1 (Days 1 -> 7) Mar. 15 -> 21	Week 2 (Days 8 -> 14) Mar. 22 -> 28	Week 3 (Days 15 -> 21) Mar. 29 -> Apr. 4	Week 4 (Days 22 -> 28) Apr. 5 -> 11	Week 5 (Days 29 -> 35) Apr. 12 -> 18	Week 6-9 (Days 36 -> 56) Apr. 19 -> May 9	Week 9 (Days 57 -> 63) May 10 -> 16	Week 10 (Days 64 -> 70) May 17 -> 25
		(cm)	(dt/ha)	(mL)	(mL)	(mL)	(mL)	(mL)	(mL)	(mL)	(mL)	(mL)
C1	1	0-90	0	1713	151	223	202	210	193	582	95	58
C2	1	0-90	30	2003	187	228	215	195	200	566	200	212
C3	1	0-90	100	2300	365	378	350	317	317	450	65	58
C4	1	0-90	300	2240	459	430	352	282	240	313	75	89
C5	1	0-90	300	1994	297	319	271	249	243	439	90	86
C6	1	0-45	0	1802	917	125	179	192	194	195	0	0
C7	1	0-45	30	2100	867	457	184	192	203	197	0	0
C8	1	0-45	100	2177	985	450	185	185	182	190	0	0
C9	1	0-45	300	1941	544	408	347	239	240	163	0	0
C10	1	0-60	0	2224	774	485	238	239	222	192	40	34
C11	1	0-60	30	2187	864	505	208	229	198	183	0	0
C12	1	0-60	100	2211	774	512	277	222	207	219	0	0
C13	1	0-60	300	1913	554	408	230	202	227	227	33	32
C-A	2	0-90	0	2125	311	340	322	295	297	421	74	65
C-B	2	0-90	30	2267	268	308	278	259	249	682	127	96
C-C	2	0-90	100	2173	242	286	246	242	232	629	170	126
C-D	2	0-90	300	1982	224	284	224	205	212	528	150	155
C-E	2	0-90	300	2183	389	347	279	252	262	452	115	87
C-F	2	0-45	0	2275	917	452	219	207	219	214	22	25
C-G	2	0-45	30	2211	885	458	217	217	215	196	1	22
C-H	2	0-45	100	2222	897	450	207	212	211	212	13	20
C-I	2	0-45	300	2415	789	476	253	217	247	286	57	90
C-J	2	0-60	0	2214	935	445	197	195	210	205	2	25
C-K	2	0-60	30	2129	914	420	185	202	202	205	1	0
C-L	2	0-60	100	2260	955	447	208	205	205	239	1	0
C-M	2	0-60	300	2420	877	457	249	225	245	224	58	85

All samples were analyzed in the BIOE Laboratory.

LEACHING RUN 1 - OCCURRENCE OF PARTICULATES IN LEACHATE

Col.	Tailings from Site	Col. Length	Applic. Rate	Week 6 (Day 36)	Week 6 (Day 37)	Week 9 (Day 58)	Week 10 (Day 65)
		(cm)	(dt/ha)				
C10	1	0-60	0			Y	Y
C13	1	0-60	300			Y	
C-A	2	0-90	0			Y	
C-F	2	0-45	0			Y	Y
C-J	2	0-60	0				Y
C-L	2	0-60	100	Y	Y		

'Y' indicates that the leachate contained particulate matter. Before further laboratory analysis, these samples were centrifuged for 20 min. at 2000 rpm. Only supernatant was used for further analysis.

LEACHING RUN 2 - QUANTITY OF LEACHATE COLLECTED

Col.	Tailings from Site	Col. Length	Applic. Rate	Total Leachate Water collected	Weekly quantity of leachate collected from 5.5 " (13.97 cm) columns (in mm). Background Measurements											
					Jul. 31	Aug. 5	Aug. 12	Week 1 (Days 1 -> 7) Aug. 16 -> 22	Week 2 (Days 8 -> 14) Aug. 23 -> 29	Week 3 (Days 15 -> 21) Aug. 30 -> Sep. 5	Week 4 (Days 22 -> 28) Sep. 6 -> 12	Week 5-8 (Days 29 -> 49) Sep. 13 -> Oct. 3	Week 8 (Days 50 -> 56) Oct. 4 -> 10	Week 9-12 (Days 57 -> 77) Oct. 11 -> 31	Week 12 (Days 78 -> 84) Nov. 1 -> 7	Week 13 (Days 85 -> 91) Nov. 8-> 14
		(cm)	(dt/ha)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)	(mm)
C1	3	0-90	0	83	1	1	2	12	7	10	9	21	7	8	4	4
C2	3	0-90	30	94	3	3	3	17	12	14	13	18	6	7	4	3
C3	3	0-90	100	82	2	2	2	12	7	9	8	22	7	12	4	1
C4	3	0-90	300	76	3	1	2	11	8	9	8	19	5	11	5	1
C5	3	0-90	300	87	3	3	3	14	10	13	9	19	6	11	4	1
C6	3	0-45	0	74	3	3	3	23	18	18	2	0	2	4	3	3
C7	3	0-45	30	74	3	0	3	19	18	18	8	0	0	4	3	3
C8	3	0-45	100	68	2	2	3	16	10	11	9	9	3	4	3	2
C9	3	0-45	300	62	3	3	2	15	9	8	6	11	3	7	3	1
C10	3	0-60	0	87	3	3	2	19	16	18	16	2	5	4	4	3
C11	3	0-60	30	83	1	0	1	11	9	12	11	24	6	6	4	1
C12	3	0-60	100	88	1	1	1	16	11	13	10	20	5	7	5	1
C13	3	0-60	300	61	1	1	0	9	7	8	8	13	4	8	2	1
C-A	4	0-90	0	97	3	1	2	16	13	15	14	16	7	5	5	5
C-B	4	0-90	30	81	1	1	1	9	8	10	10	22	6	9	5	2
C-C	4	0-90	100	95	4	3	4	24	15	14	12	11	5	8	5	2
C-D	4	0-90	300	94	1	1	4	20	14	15	11	19	4	7	2	1
C-E	4	0-90	300	52	1	1	1	10	6	8	7	12	2	5	1	1
C-F	4	0-45	0	100	3	1	1	28	22	22	2	0	6	6	7	8
C-G	4	0-45	30	92	3	2	3	32	18	19	2	0	3	5	5	7
C-H	4	0-45	100	98	3	1	3	15	42	20	2	0	4	5	4	6
C-I	4	0-45	300	90	3	2	3	20	13	14	9	13	5	10	3	2
C-J	4	0-60	0	93	3	1	2	15	13	16	15	13	7	5	6	4
C-K	4	0-60	30	87	2	1	1	12	10	13	12	19	6	6	6	3
C-L	4	0-60	100	90	3	3	2	15	12	14	12	15	6	7	6	3
C-M	4	0-60	300	90	3	3	2	16	12	13	10	15	6	11	5	2

All samples were analyzed in the BIOE Laboratory.

LEACHING RUN 2 - QUANTITY OF LEACHATE COLLECTED

Col.	Tailings from Site	Col. Length	Applic. Rate	Total Leachate Water collected	Weekly quantity of leachate collected from 5.5 " (13.97 cm) columns. Background Measurements Jul. 31	Aug. 5	Aug. 12	Week 1 (Days 1 -> 7) Aug. 16 -> 22	Week 2 (Days 8 -> 14) Aug. 23 -> 29	Week 3 (Days 15 -> 21) Aug. 30 -> Sep. 5	Week 4 (Days 22 -> 28) Sep. 6 -> 12	Week 5-8 (Days 29 -> 49) Sep. 13 -> Oct. 3	Week 8 (Days 50 -> 56) Oct. 4 -> 10	Week 9-12 (Days 57 -> 77) Oct. 11 -> 31	Week 12 (Days 78 -> 84) Nov. 1 -> 7	Week 13 (Days 85 -> 91) Nov. 8-> 14
		(cm)	(dt/ha)	(mL)	(mL)	(mL)	(mL)	(mL)	(mL)	(mL)	(mL)	(mL)	(mL)	(mL)	(mL)	(mL)
C1	3	0-90	0	1275	20	10	25	191	112	155	139	322	114	122	65	55
C2	3	0-90	30	1435	50	45	40	263	180	221	202	280	90	100	56	43
C3	3	0-90	100	1258	25	25	30	191	113	132	121	338	106	180	59	18
C4	3	0-90	300	1166	50	8	30	167	119	133	125	286	79	167	70	20
C5	3	0-90	300	1327	45	40	40	213	149	192	141	288	96	163	64	21
C6	3	0-45	0	1131	45	40	45	353	281	279	34	0	27	64	43	50
C7	3	0-45	30	1135	50	2	45	292	282	280	130	2	0	63	41	45
C8	3	0-45	100	1041	30	30	40	249	153	173	144	138	43	66	45	30
C9	3	0-45	300	954	40	40	30	227	133	130	91	167	53	100	39	14
C10	3	0-60	0	1339	50	45	30	290	242	277	244	35	80	63	58	50
C11	3	0-60	30	1279	8	5	8	162	140	177	161	375	96	86	62	20
C12	3	0-60	100	1343	15	8	10	243	173	196	152	310	84	101	69	15
C13	3	0-60	300	935	8	8	5	144	107	125	129	203	57	116	38	16
C-A	4	0-90	0	1481	45	10	25	252	203	224	208	250	112	75	75	82
C-B	4	0-90	30	1243	20	10	10	143	115	153	150	335	98	144	77	28
C-C	4	0-90	100	1464	55	50	55	365	229	214	184	172	80	115	80	26
C-D	4	0-90	300	1435	20	10	55	312	214	224	164	298	63	108	38	14
C-E	4	0-90	300	801	18	8	10	153	89	121	110	178	38	82	22	8
C-F	4	0-45	0	1527	45	20	10	422	334	337	33	0	87	87	102	125
C-G	4	0-45	30	1413	50	30	50	492	280	293	36	0	51	78	75	108
C-H	4	0-45	100	1500	45	10	40	227	645	301	25	2	67	78	65	90
C-I	4	0-45	300	1376	45	35	45	314	197	209	140	198	77	152	52	37
C-J	4	0-60	0	1430	45	20	30	229	203	240	233	193	102	77	86	67
C-K	4	0-60	30	1341	35	15	15	179	153	203	182	295	95	88	96	50
C-L	4	0-60	100	1374	50	40	35	231	180	209	189	235	86	112	87	45
C-M	4	0-60	300	1378	40	50	35	240	179	201	158	231	92	171	73	33

All samples were analyzed in the BIOE Laboratory.

LEACHING RUN 2 - OCCURRENCE OF PARTICULATES IN LEACHATE

Col.	Tailings from Site	Col. Length	Applic. Rate	Week 2 (Day 9)	Week 2 (Day 10)	Week 3 (Day 16)	Week 8 (Day 51)	Week 9 (Day 57)	Week 9 (Day 58)	Week 12 (Day 79)	Week 12 (Day 80)	Week 13 (Day 85)	Week 13 (Day 86)
		(cm)	(dt/ha)										
C-A	4	0-90	0				Y	Y	Y	Y			Y
C-F	4	0-45	0				Y	Y	Y	Y	Y	Y	Y
C-G	4	0-45	30				Y	Y		Y	Y		Y
C-H	4	0-45	100	Y	Y	Y	Y	Y	Y	Y		Y	Y

'Y' indicates that the leachate contained particulate matter. Before further laboratory analysis, these samples were centrifuged for 20 min. at 2000 rpm. Only supernatant was used for further analysis.

LEACHING RUN 2 - STANDING WATER COLUMN ON TOP OF TEST COLUMNS

Col.	Tailings from Site	Col. Length	Applic. Rate	Week 2 (Day 9)	Week 2 (Day 12)	Week 3 (Day 17)	Week 4 (Day 22)	Week 4 (Day 25)	Week 5 (Day 29)	Week 5 (Day 31)	Week 5 (Day 33)	Week 6 (Day 36)	Week 6 (Day 38)	Week 6 (Day 40)	Week 7 (Day 45)
		(cm)	(dt/ha)	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)
C1	3	0-90	0	4.5	2.4	5.0	4.0	3.2	2.8	2.5	1.9	1.3	0.7	0	0
C2	3	0-90	30	4.5	4.5	4.8	3.0	2.5	1.2	0.5	0	0	0	0	0
C3	3	0-90	100	3.8	3.0	4.5	3.7	2.9	2.3	2.5	0.9	0.8	0.6	0.5	0
C4	3	0-90	300	2.5	1.4	2.5	1.5	0.9	0	0	0	0	0	0	0
C5	3	0-90	300	2.0	1.0	2.5	0.5	0	0	0	0	0	0	0	0
C6	3	0-45	0	2.5	1.8	1.8	0	0	0	0	0	0	0	0	0
C7	3	0-45	30	2.2	1.5	2.5	0.5	0	0	0	0	0	0	0	0
C8	3	0-45	100	2.4	2.0	2.5	1.5	0.9	0	0	0	0	0	0	0
C9	3	0-45	300	1.5	0.5	2.0	0.5	0	0	0	0	0	0	0	0
C10	3	0-60	0	5.0	3.5	4.5	2.5	1.5	0	0	0	0	0	0	0
C11	3	0-60	30	5.0	5.0	6.0	4.5	3.6	2.5	2.6	1.9	1.8	1.5	1.4	0
C12	3	0-60	100	3.8	3.0	3.8	2.5	2.3	1.0	1.0	0.5	0	0	0	0
C13	3	0-60	300	2.0	1.5	2.5	1.5	1.8	1.0	0	0	0	0	0	0
C-A	4	0-90	0	4.6	4.3	4.8	3.8	2.0	0.5	0	0	0	0	0	0
C-B	4	0-90	30	4.9	4.2	5.5	4.0	2.9	2.4	1.8	1.3	0	0	0	0
C-C	4	0-90	100	4.9	1.4	1.5	1.0	0	0	0	0	0	0	0	0
C-D	4	0-90	300	5.3	0.0	1.0	0	0	0	0	0	0	0	0	0
C-E	4	0-90	300	2.5	1.0	2.0	1.0	0.8	0	0	0	0	0	0	0
C-F	4	0-45	0	1.5	1.0	1.5	0	0	0	0	0	0	0	0	0
C-G	4	0-45	30	2.5	1.0	2.0	0	0	0	0	0	0	0	0	0
C-H	4	0-45	100	3.0	0.8	0.5	0	0	0	0	0	0	0	0	0
C-I	4	0-45	300	2.0	1.0	2.0	0	0	0	0	0	0	0	0	0
C-J	4	0-60	0	2.5	3.8	4.3	2.8	1.8	0.5	0	0	0	0	0	0
C-K	4	0-60	30	1.8	4.2	4.6	3.7	2.7	1.8	1.3	0.8	0	0	0	0
C-L	4	0-60	100	3.4	2.5	3.4	2.5	1.8	0.8	0.7	0	0	0	0	0
C-M	4	0-60	300	1.8	1.0	2.5	0.5	0	0	0	0	0	0	0	0

LEACHING RUN 1 - TEMPERATURE REGIME

LEACHING RUN 1	Temp. at	Temp. at	Temp. at	Temp. at	Temp. at	Temp. at	Temp. at	Temp. at	Temp. at	Temp. at	Temp. at	Temp. at	Weekly Average Temp.	Std. Dev.	C.V.
Time of day:	1:00	3:00	5:00	7:00	9:00	11:00	13:00	15:00	17:00	19:00	21:00	23:00			
	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)		(%)
Week 1 Mar. 14 -> 20	15.9	15.6	15.2	15.0	14.7	15.0	15.2	15.8	15.7	16.1	14.0	15.4	15.3	0.6	4%
Week 2 Mar. 21 -> 27	15.9	15.4	15.2	14.9	15.0	14.9	15.1	17.4	18.2	17.8	17.2	16.7	16.1	1.3	8%
Week 3 Mar. 28 -> Apr. 3	16.1	15.7	15.4	15.2	14.9	14.9	15.1	16.1	17.3	17.1	16.7	16.4	15.9	0.8	5%
Week 4 Apr. 4 -> 10	15.9	15.5	15.1	14.9	14.9	14.9	15.0	15.8	16.9	16.7	16.4	16.1	15.7	0.8	5%
Week 5 Apr. 11 -> 17	16.7	16.5	16.2	16.1	15.8	15.9	16.2	16.7	18.2	18.0	17.6	17.2	16.8	0.8	5%
Week 6 Apr. 18 -> 24	18.1	17.7	17.3	17.1	16.7	16.7	17.0	18.1	20.0	20.1	19.4	18.7	18.1	1.2	7%
Week 7 Apr. 25 -> May 1	17.9	17.5	17.2	16.9	16.8	16.9	17.3	17.7	19.0	18.7	18.3	17.9	17.7	0.7	4%
Week 8 May 2 -> 8	18.1	17.6	17.3	17.2	17.2	17.3	17.7	18.4	20.8	20.3	19.5	18.9	18.4	1.3	7%
Week 9 May 9 -> 15	20.7	20.3	19.9	19.5	19.5	19.6	19.8	20.6	24.2	23.7	22.7	21.8	21.0	1.7	8%
Week 10 May 16 -> 20	23.6	22.8	22.4	21.9	20.8	21.0	22.4	23.5	26.3	26.1	25.3	24.4	23.4	1.9	8%

Average Temperature (°C): **17.8**

Notes:

The average temperature values for specified times of day were calculated from daily averages for these specified times. The daily average for a specified time was calculated from 10 measurements collected from 10 columns (in the 0-15 cm profile).

LEACHING RUN 2 - TEMPERATURE REGIME

LEACHING RUN 2	Temp. at	Temp. at	Temp. at	Temp. at	Temp. at	Temp. at	Temp. at	Temp. at	Temp. at	Temp. at	Temp. at	Temp. at	Weekly Average Temp.	Std. Dev.	C.V.
Time of day:	1:00	3:00	5:00	7:00	9:00	11:00	13:00	15:00	17:00	19:00	21:00	23:00			
	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)		(%)
Week 1 Aug. 16 -> 22	21.2	21.0	20.9	20.6	20.5	20.5	20.6	20.7	20.9	21.1	21.1	21.1	20.8	0.3	1%
Week 2 Aug. 23 -> 29	19.7	19.6	19.5	19.3	19.1	19.2	19.4	19.6	20.0	20.1	20.1	20.0	19.6	0.4	2%
Week 3 Aug. 30 -> Sep. 5	21.2	21.0	20.9	20.6	20.4	20.5	20.6	21.0	21.4	21.6	21.6	21.5	21.0	0.4	2%
Week 4 Sep. 6 -> 12	20.4	20.3	20.0	19.6	19.6	19.4	19.6	19.9	20.2	20.3	20.2	20.1	20.0	0.3	2%
Week 5 Sep. 13 -> 19	17.3	17.2	17.0	16.8	16.5	16.6	16.8	17.3	17.4	17.5	17.4	17.3	17.1	0.4	2%
Week 6 Sep. 20 -> 26	16.0	16.1	15.9	15.6	15.7	15.6	15.8	16.2	16.6	16.7	16.7	16.8	16.1	0.5	3%
Week 7 Sep. 27 -> Oct. 3	18.3	18.2	18.0	17.8	17.6	17.8	18.0	18.5	18.8	18.8	18.8	18.7	18.3	0.4	2%
Week 8 Oct. 4 -> 10	16.4	16.2	16.0	15.9	15.8	15.6	15.8	16.2	16.3	16.3	16.2	16.1	16.1	0.3	2%
Week 9 Oct. 11 -> 17	15.7	15.6	15.5	15.3	15.3	15.4	15.5	15.6	15.8	15.7	15.7	15.6	15.6	0.2	1%
Week 10 Oct. 18 -> 24	15.7	15.5	15.4	15.4	15.3	15.2	15.4	15.5	15.6	15.8	15.7	15.6	15.5	0.2	1%
Week 11 Oct. 25 -> 31	13.9	13.8	13.6	13.6	13.6	13.4	13.7	14.0	14.1	14.2	14.3	14.2	13.9	0.3	2%
Week 12 Nov. 1 -> 7	16.4	16.3	16.2	15.9	15.8	15.9	15.9	16.2	16.4	16.3	16.3	16.2	16.1	0.2	1%
Week 13 Nov. 8 -> 13	14.0	14.1	13.9	13.9	13.8	13.7	13.9	14.2	14.5	14.5	14.4	14.4	14.1	0.3	2%

Average Temperature (°C): 17.2

Notes:

The average temperature values for specified times of day were calculated from daily averages for these specified times. The daily average for a specified time was calculated from 10 measurements collected from 10 columns (in the 0-15 cm profile).

APPENDIX D

Leaching Run 1 - Soil Nitrogen, pH, and EC

LEACHING RUN 1 - NITROGEN BALANCE IN THE 0-45 cm LAYER

Class Level Information

Class	Levels	Values			
LENGTH	3	_0-45 cm Col.		_0-60 cm Col.	_0-90 cm Col.
APPL	4	_ 0 dt/ha	_ 30 dt/ha	_100 dt/ha	_300 dt/ha

Number of observations in data set = 26 (DF for Error = 14)

Notes:
All samples were analyzed in the BIOE Lab.
The factorial model with parameters LENGTH (column length) and APPL (application rate) was run on the data.
The Duncan multiple range test at the 0.05 level of probability was used to determine significantly different means. This test controls the type I comparisonwise error rate, not the experimentwise error rate.
'N' refers to the number of samples for average calculations.
Means preceded by different letters are significantly different.

Start Soil N (mg N/column):

Duncan Grouping	Mean	N	APPL
A	16551	8	_300 dt/ha
B	5612	6	_100 dt/ha
C	1781	6	_ 30 dt/ha
D	138	6	_ 0 dt/ha

End Soil N (mg N/column):

Duncan Grouping	Mean	N	APPL
A	11647	8	_300 dt/ha
B	4577	6	_100 dt/ha
C	1263	6	_ 30 dt/ha
C	129	6	_ 0 dt/ha

Soil N lost (mg N/column):

Duncan Grouping	Mean	N	APPL
A	4904	8	_300 dt/ha
B	1036	6	_100 dt/ha
B	518	6	_ 30 dt/ha
B	9	6	_ 0 dt/ha

LEACHING EXPERIMENT - RUN1 - NITROGEN, pH, EC - OVERVIEW

Class Level Information

Class	Levels	Values			
Data for 0-45 cm Layers:					
APPL	4	_ 0 dt/ha _ 30 dt/ha	_100 dt/ha _300 dt/ha		
LENGTH	3	_0-45 cm Col.	_0-60 cm Col.	_0-90 cm Col.	
Number of observations in data set = 26			(DF for Error = 14)		
Data for 45-60 cm Layer:					
APPL	4	_ 0 dt/ha _ 30 dt/ha	_100 dt/ha _300 dt/ha		
LENGTH	2	_0-60 cm Col.	_0-90 cm Col.		
Number of observations in data set = 18			(DF for Error = 10)		
Data for 60-90 cm Layers:					
APPL	4	_ 0 dt/ha _ 30 dt/ha	_100 dt/ha _300 dt/ha		
LENGTH	1	_0-90 cm Col.			
Number of observations in data set = 10			(DF for Error = 6)		

LEACHING RUN 1						
DEPTH:		1:2 pH	1:2 EC	TKN	NH3	NO3-N
			(dS/m)	(mg/kg)	(mg/kg)	(mg/kg)
0 - 15 cm	Mean	7.3	APPL sig.	APPL sig.	41.2	APPL sig.
	Std. Dev.	0.2			125.6	
15 - 30 cm	Mean	7.5	APPL sig.	APPL sig.	LENGTH	14.6
	Std. Dev.	0.2			sig.	14.2
30 - 45 cm	Mean	7.6	APPL sig.	41.7	14.6	APPL and
	Std. Dev.	0.2		32.9	31.5	LENGTH sig.
45 - 60 cm	Mean	7.5	0.3	19.5	3.0	0.2
	Std. Dev.	0.3	0.1	5.0	2.3	
60 - 75 cm	Mean	7.6	0.3	24.1	3.6	0.2
	Std. Dev.	0.1	0.1	8.9	1.7	
75 - 90 cm	Mean	7.6	0.4	21.9	APPL sig.	0.2
	Std. Dev.	0.1	0.1	5.2		

Notes:
All samples were analyzed in the BIOE Lab.
The factorial model y=LENGTH|APPL and the Duncan multiple range test at the 0.05 level of probability was used to determine significantly different means.
'Std. Dev. ' refers to the sample standard deviation.

LEACHING EXPERIMENT - RUN1 - NITROGEN, pH, EC - SIG. PARAMETERS

Class	Levels	Values			
Data Analysis for 0-15, 15-30, and 30-45 cm Layers:					
APPL	4	_ 0 dt/ha	_ 30 dt/ha	_100 dt/ha	_300 dt/ha
LENGTH	3	_0-45 cm Col.	_0-60 cm Col.		_0-90 cm Col.
Number of observations in data set = 26				(DF for Error = 14)	
Data Analysis for 45-60 cm Layer:					
APPL	4	_ 0 dt/ha	_ 30 dt/ha	_100 dt/ha	_300 dt/ha
LENGTH	2	_0-60 cm Col.		_0-90 cm Col.	
Number of observations in data set = 18				(DF for Error = 10)	
Data Analysis for 60-75 and 75-90 cm Layers:					
APPL	4	_ 0 dt/ha	_ 30 dt/ha	_100 dt/ha	_300 dt/ha
LENGTH	1	_0-90 cm Col.			
Number of observations in data set = 10				(DF for Error = 6)	

Notes:
All samples were analyzed in the BIOE Lab.
The factorial model y=LENGTH|APPL and the Duncan multiple range test at the 0.05 level of probability were used to determine significantly different means.
Means followed or preceded by different letters are significantly different.
'N' refers to the number of samples for average calculations.

TKN (mg/kg)				
Depth / Appl.:	0 dt/ha	30 dt/ha	100 dt/ha	300 dt/ha
0 - 15 cm	22 c	490 c	1917 b	5502 a
15 - 30 cm	21 b	45 b	250 b	2243 a
30 - 45 cm	avg. value:	42		
45 - 60 cm	avg. value:	20		
60 - 75 cm	avg. value:	24		
75 - 90 cm	avg. value:	22		

NO3-N (mg/kg)				
Depth / Appl.:	0 dt/ha	30 dt/ha	100 dt/ha	300 dt/ha
0 - 15 cm	0.2 b	38 b	139 a	211 a
15 - 30 cm	avg. value:	15		
30 - 45 cm *	0.2 b	0.4 b	2.3 a	0.8 b
45 - 60 cm	avg. value:	0.2		
60 - 75 cm	avg. value:	0.2		
75 - 90 cm	avg. value:	0.2		

* The concentration of NO3-N is also dependent on the length of the columns.
30-45 cm NO3-N (mg/kg):

Duncan Group.	Mean	N	LENGTH
a	1.9	8	_0-45 cm Col.
b	0.5	8	_0-60 cm Col.
b	0.4	10	_0-90 cm Col.

15-30 cm NH4-N (mg/kg):

Duncan Group.	Mean	N	LENGTH
a	78	10	_0-90 cm Col.
b	14	8	_0-60 cm Col.
b	13	8	_0-45 cm Col.

75-90 cm NH4-N (mg/kg):

Duncan Group.	Mean	N	APPL
a	6.4	2	_ 0 dt/ha
b	3.3	2	_100 dt/ha
b	3.3	2	_ 30 dt/ha
b	1.8	4	_300 dt/ha

LEACHING EXPERIMENT - RUN1 - NITROGEN, pH, EC - SIG. PARAMETERS

1:2 EC (dS/m)				
Depth / Appl.:	0 dt/ha	30 dt/ha	100 dt/ha	300 dt/ha
0 - 15 cm	0.1 c	0.4 c	1 b	2 a
15 - 30 cm	0.2 c	0.2 c	0.3 b	0.8 a
30 - 45 cm	0.2 c	0.2 c	0.3 b	0.4 a
45 - 60 cm	avg. value:	0.3		
60 - 75 cm	avg. value:	0.3		
75 - 90 cm	avg. value:	0.4		

LEACHING EXPERIMENT - RUN 1 - LABORATORY DATA - NITROGEN, pH, EC, LOI

								Background Nitrogen in Tailings			Nitrogen added with Biosolids			Nitrogen at the End of the Run				Total N	Total N	Nitrogen Concentration at the End of the Run		
		Tailings					Loss										Mineral	at Start	at End			
		from	Column	Appl.	1:2	1:2	on	TKN	NH4-N	NO3-N	TKN	NH4-N	NO3-N	TKN	NH4-N	NO3-N	Nitrogen	of	of			
Col.:	Depth:	Site:	Length:	Rate:	pH:	EC:	Ignition:	Backg.	Backg.	Backg.	added:	added:	added:	at End	at End	at End	at End	Run	Run	TKN:	NH4-N:	NO3-N:
	(cm)		(cm)	(dt/ha)		(dS/m)	(@450°C)	(kg N/ ha)	(kg N/ ha)	(kg N/ ha)	(kg N/ ha)	(kg N/ ha)	(kg N/ ha)	(kg N/ ha)	(kg N/ ha)	(kg N/ ha)	(kg N/ ha)	(kg N/ ha)	(kg N/ ha)	(mg N/ kg)	(mg N/ kg)	(mg N/ kg)
C1	0-15	1	0-90	0	7.9	0.12	n/a	31	2.0	0.7	0	0	0.00	30	9	< 1	10	33	30	19	5.7	< 0.7
C1	15-30	1	0-90	0	7.7	0.13	n/a	37	6.9	1.2	0	0	0.00	37	8	< 1	10	38	37	22	5.2	< 0.7
C1	30-45	1	0-90	0	7.5	0.19	n/a	27	13.8	0.9	0	0	0.00	30	< 5	< 0.5	< 6	29	30	19	< 3.5	< 0.3
C1	45-60	1	0-90	0	7.6	0.25	n/a	32	13.9	1.0	0	0	0.00	38	< 6	< 0.5	< 6	33	38	23	< 3.5	< 0.3
C1	60-75	1	0-90	0	7.5	0.24	n/a	61	0.1	1.0	0	0	0.00	70	12	< 1	13	62	70	38	6.7	< 0.3
C1	75-90	1	0-90	0	7.6	0.40	n/a	57	30.7	0.9	0	0	0.00	43	12	< 1	12	59	43	23	6.2	< 0.3
C2	0-15	1	0-90	30	7.7	0.26	n/a	29	1.8	0.7	971	100	0.05	785	42	< 3	45	1001	785	525	28.3	< 2.0
C2	15-30	1	0-90	30	7.9	0.14	n/a	40	7.1	1.3	100	10	0.01	74	33	< 1	35	142	74	40	18.1	< 0.7
C2	30-45	1	0-90	30	7.8	0.14	n/a	27	13.8	0.9	0	0	0.00	29	< 5	< 0.5	< 6	29	29	18	< 3.5	< 0.3
C2	45-60	1	0-90	30	7.6	0.18	n/a	32	13.9	1.0	0	0	0.00	31	< 6	< 0.5	< 6	33	31	19	< 3.5	< 0.3
C2	60-75	1	0-90	30	7.6	0.30	n/a	61	0.1	1.0	0	0	0.00	44	< 7	< 1	< 7	62	44	24	< 3.5	< 0.3
C2	75-90	1	0-90	30	7.6	0.34	n/a	57	30.7	0.9	0	0	0.00	48	< 7	< 1	< 7	59	48	25	< 3.5	< 0.3
C3	0-15	1	0-90	100	7.2	1.30	n/a	24	1.5	0.5	2748	283	0.14	2429	6	289	295	2773	2717	1837	4.4	219
C3	15-30	1	0-90	100	7.7	0.32	n/a	37	5.9	1.1	825	85	0.05	581	179	48	226	862	629	339	104	27.6
C3	30-45	1	0-90	100	7.7	0.23	n/a	36	17.9	1.2	0	0	0.00	55	< 7	3	10	37	59	29	< 3.5	1.6
C3	45-60	1	0-90	100	7.5	0.34	n/a	32	13.9	1.0	0	0	0.00	37	< 6	< 0.5	< 6	33	37	22	< 3.5	< 0.3
C3	60-75	1	0-90	100	7.6	0.41	n/a	61	0.1	1.0	0	0	0.00	64	< 7	< 1	< 7	62	64	35	< 3.5	< 0.3
C3	75-90	1	0-90	100	7.5	0.42	n/a	57	30.7	0.9	0	0	0.00	53	< 7	< 1	< 7	59	53	28	< 3.5	< 0.3
C4	0-15	1	0-90	300	7.1	2.30	n/a	16	1.0	0.3	5359	552	0.29	5040	12	254	265	5376	5293	5255	12.3	265
C4	15-30	1	0-90	300	7.3	1.20	n/a	16	1.0	0.3	5359	552	0.29	3110	43	8	51	5376	3118	3243	44.8	8.3
C4	30-45	1	0-90	300	7.8	0.40	n/a	42	9.2	1.4	0	0	0.00	367	307	2	308	43	369	189	158	1
C4	45-60	1	0-90	300	7.5	0.34	n/a	35	16.9	1.2	0	0	0.00	53	< 7	< 1	< 7	37	53	27	< 3.5	< 0.3
C4	60-75	1	0-90	300	7.5	0.32	n/a	53	8.5	1.2	0	0	0.00	52	< 7	< 1	< 8	54	52	26	< 3.5	< 0.3
C4	75-90	1	0-90	300	7.5	0.39	n/a	67	20.3	1.0	0	0	0.00	49	< 7	< 1	< 8	67	49	23	< 3.5	< 0.3
C5	0-15	1	0-90	300	7.5	2.30	n/a	22	1.0	0.3	5359	552	0.29	5003	427	10	437	5381	5013	5217	445	10.3
C5	15-30	1	0-90	300	7.7	0.94	n/a	22	1.0	0.3	5359	552	0.29	4310	222	3	226	5381	4314	4494	232	3.3
C5	30-45	1	0-90	300	7.8	0.35	n/a	37	12.9	0.9	0	0	0.00	216	22	1	22	38	217	111	11.2	0.3
C5	45-60	1	0-90	300	7.7	0.25	n/a	45	7.8	0.7	0	0	0.00	40	< 7	< 1	< 7	46	40	20	< 3.5	< 0.3
C5	60-75	1	0-90	300	7.6	0.32	n/a	45	9.8	0.8	0	0	0.00	47	< 7	< 1	< 8	46	47	23	< 3.5	< 0.3
C5	75-90	1	0-90	300	7.7	0.34	n/a	63	30.7	1.0	0	0	0.00	59	< 7	< 1	< 8	65	59	28	< 3.5	< 0.3

All samples were analyzed in the BIOE Laboratory.

LEACHING EXPERIMENT - RUN 1 - LABORATORY DATA - NITROGEN, pH, EC, LOI

Col.:	Depth: (cm)	Tailings from Site:	Column Length: (cm)	Appl. Rate: (dt/ha)	1:2 pH:	1:2 EC: (dS/m)	Loss on Ignition: (@450°C)	Background Nitrogen in Tailings: TKN Backg. (kg N/ ha)	NH4-N Backg. (kg N/ ha)	NO3-N Backg. (kg N/ ha)	Nitrogen added with Biosolids: TKN added: (kg N/ ha)	NH4-N added: (kg N/ ha)	NO3-N added: (kg N/ ha)	Nitrogen at the End of the Run: TKN at End (kg N/ ha)	NH4-N at End (kg N/ ha)	NO3-N at End (kg N/ ha)	Mineral Nitrogen at End (kg N/ ha)	Total N at Start of Run (kg N/ ha)	Total N at End of Run (kg N/ ha)	Nitrogen Concentration at the End of the Run: TKN: (mg N/ kg)	NH4-N: (mg N/ kg)	NO3-N: (mg N/ kg)
C6	0-15	1	0-45	0	7.5	0.14	n/a	31	2.0	0.7	0	0	0.00	38	6	< 1	7	33	38	23	3.4	< 0.6
C6	15-30	1	0-45	0	7.4	0.18	n/a	37	6.9	1.2	0	0	0.00	25	< 6	1	7	38	26	15	< 3.5	0.5
C6	30-45	1	0-45	0	7.5	0.13	n/a	27	13.8	0.9	0	0	0.00	30	< 5	< 0.5	< 6	29	30	20	< 3.5	< 0.3
C7	0-15	1	0-45	30	7.3	0.44	n/a	29	1.8	0.7	971	100	0.05	581	6	83	89	1001	665	389	4.1	55.9
C7	15-30	1	0-45	30	7.4	0.20	n/a	40	7.1	1.3	100	10	0.01	49	10	28	38	142	77	27	5.4	15.1
C7	30-45	1	0-45	30	7.4	0.20	n/a	27	13.8	0.9	0	0	0.00	85	< 5	2	7	29	87	55	< 3.5	1
C8	0-15	1	0-45	100	7.3	1.00	n/a	24	1.5	0.5	2748	283	0.14	2142	5	177	183	2773	2319	1620	3.7	134
C8	15-30	1	0-45	100	7.5	0.32	n/a	37	5.9	1.1	825	85	0.05	326	48	85	133	862	412	190	27.9	49.9
C8	30-45	1	0-45	100	7.3	0.45	n/a	36	15.3	1.2	0	0	0.00	57	17	5	22	37	62	30	8.9	2.6
C9	0-15	1	0-45	300	7.4	2.40	n/a	16	1.0	0.3	5359	552	0.29	7410	399	244	643	5376	7653	7726	416	254
C9	15-30	1	0-45	300	7.6	0.70	n/a	16	1.0	0.3	5359	552	0.29	1419	24	41	65	5376	1460	1480	25.1	43.1
C9	30-45	1	0-45	300	7.7	0.45	n/a	42	9.2	1.4	0	0	0.00	91	36	1	37	43	91	47	18.6	0.3
C10	0-15	1	0-60	0	7.8	0.13	n/a	31	2.0	0.7	0	0	0.00	27	< 6	< 0.5	< 6	33	27	19	< 3.5	< 0.3
C10	15-30	1	0-60	0	7.8	0.12	n/a	37	6.9	1.2	0	0	0.00	30	< 6	< 0.5	< 6	38	30	24	< 3.5	< 0.3
C10	30-45	1	0-60	0	7.4	0.21	n/a	27	13.8	0.9	0	0	0.00	38	< 5	< 0.5	< 6	29	38	25	< 3.5	< 0.3
C10	45-60	1	0-60	0	7.7	0.14	n/a	32	13.9	1.0	0	0	0.00	29	< 6	< 0.5	< 6	33	29	17	< 3.5	< 0.3
C11	0-15	1	0-60	30	7.4	0.49	n/a	27	1.8	0.6	938	97	0.05	756	< 5	93	98	966	849	544	< 3.5	67
C11	15-30	1	0-60	30	7.5	0.18	n/a	41	7.1	1.3	134	14	0.01	209	22	36	57	177	245	116	12	20
C11	30-45	1	0-60	30	7.6	0.25	n/a	30	15.0	1.0	0	0	0.00	34	< 5	< 0.5	< 6	31	34	20	< 3.5	< 0.3
C11	45-60	1	0-60	30	7.8	0.18	n/a	32	13.9	1.0	0	0	0.00	39	< 6	< 0.5	< 6	33	39	24	< 3.5	< 0.3
C12	0-15	1	0-60	100	7.3	1.00	n/a	24	1.5	0.5	2748	283	0.14	1855	5	192	198	2773	2047	1403	4.2	145
C12	15-30	1	0-60	100	7.7	0.38	n/a	37	5.9	1.1	825	85	0.05	728	45	52	97	862	779	425	26.4	30.1
C12	30-45	1	0-60	100	7.7	0.26	n/a	36	15.3	1.2	0	0	0.00	63	16	1	17	37	64	33	8.5	0.5
C12	45-60	1	0-60	100	7.9	0.22	n/a	32	13.9	1.0	0	0	0.00	35	< 6	< 0.5	< 6	33	35	21	< 3.5	< 0.3
C13	0-15	1	0-60	300	7.3	1.50	n/a	16	1.0	0.3	5359	552	0.29	6145	10	155	165	5376	6300	6407	10.4	162
C13	15-30	1	0-60	300	7.5	0.87	n/a	16	1.0	0.3	5359	552	0.29	2811	48	50	98	5376	2861	2931	49.8	52
C13	30-45	1	0-60	300	7.6	0.26	n/a	42	9.2	1.4	0	0	0.00	81	46	1	46	43	82	42	23.6	0.3
C13	45-60	1	0-60	300	7.6	0.30	n/a	35	16.9	1.2	0	0	0.00	52	< 7	< 1	< 7	37	52	27	< 3.5	< 0.3

All samples were analyzed in the BIOE Laboratory.

LEACHING EXPERIMENT - RUN 1 - LABORATORY DATA - NITROGEN, pH, EC, LOI

Col.:	Depth: (cm)	Tailings from Site:	Column Length: (cm)	Appl. Rate: (dt/ha)	1:2 pH:	1:2 EC: (dS/m)	Loss on Ignition: (@450°C)	Background Nitrogen in Tailings: TKN Backg. (kg N/ha)	NH4-N Backg. (kg N/ha)	NO3-N Backg. (kg N/ha)	Nitrogen added with Biosolids: TKN added: (kg N/ha)	NH4-N added: (kg N/ha)	NO3-N added: (kg N/ha)	Nitrogen at the End of the Run: TKN at End (kg N/ha)	NH4-N at End (kg N/ha)	NO3-N at End (kg N/ha)	Mineral Nitrogen at End (kg N/ha)	Total N at Start of Run (kg N/ha)	Total N at End of Run (kg N/ha)	Nitrogen Concentration at the End of the Run: TKN: (mg N/kg)	NH4-N: (mg N/kg)	NO3-N: (mg N/kg)
C-A	0-15	2	0-90	0	7.3	0.15	n/a	31	1.6	0.5	0	0	0.00	25	6	< 0.3	6	31	25	21	5	< 0.3
C-A	15-30	2	0-90	0	7.3	0.16	n/a	22	7.7	0.6	0	0	0.00	20	7	< 0.3	8	22	20	17	6.2	< 0.3
C-A	30-45	2	0-90	0	7.3	0.17	n/a	27	6.9	0.4	0	0	0.00	20	< 4	< 0.3	4	27	20	17	< 3.5	< 0.3
C-A	45-60	2	0-90	0	7.3	0.24	n/a	40	0.1	0.7	0	0	0.00	21	12	< 0.5	12	40	21	12	7	< 0.3
C-A	60-75	2	0-90	0	7.3	0.32	n/a	43	19.4	0.8	0	0	0.00	25	14	< 1	14	44	25	13	7	< 0.3
C-A	75-90	2	0-90	0	7.3	0.42	n/a	69	34.6	1.0	0	0	0.00	29	12	< 1	13	70	29	15	6.5	< 0.3
C-B	0-15	2	0-90	30	7.2	0.44	n/a	31	1.6	0.5	1072	110	0.06	561	15	87	102	1104	648	469	12.4	72.8
C-B	15-30	2	0-90	30	7.5	0.20	n/a	22	7.7	0.6	0	0	0.00	30	42	8	50	22	38	26	37.2	6.7
C-B	30-45	2	0-90	30	7.5	0.20	n/a	27	6.9	0.4	0	0	0.00	23	8	< 0.3	8	27	23	20	6.8	< 0.3
C-B	45-60	2	0-90	30	7.5	0.25	n/a	40	0.1	0.7	0	0	0.00	33	14	< 0.5	15	40	33	19	8.4	< 0.3
C-B	60-75	2	0-90	30	7.6	0.38	n/a	43	19.4	0.8	0	0	0.00	42	7	< 1	8	44	42	21	3.7	< 0.3
C-B	75-90	2	0-90	30	7.7	0.45	n/a	69	34.6	1.0	0	0	0.00	40	9	< 1	10	70	40	21	4.8	< 0.3
C-C	0-15	2	0-90	100	7.4	0.72	n/a	16	0.8	0.2	3227	333	0.17	2226	43	107	150	3243	2333	1945	37.4	93
C-C	15-30	2	0-90	100	8.0	0.28	n/a	24	7.8	0.6	346	36	0.02	313	37	33	70	371	346	248	29.3	26.1
C-C	30-45	2	0-90	100	7.7	0.24	n/a	27	6.9	0.4	0	0	0.00	23	10	< 0.3	11	27	23	20	8.8	< 0.3
C-C	45-60	2	0-90	100	7.6	0.22	n/a	42	1.4	0.8	0	0	0.00	25	11	< 1	12	43	25	14	6.1	< 0.3
C-C	60-75	2	0-90	100	7.6	0.26	n/a	48	22.3	0.9	0	0	0.00	42	14	< 1	14	49	42	20	6.7	< 0.3
C-C	75-90	2	0-90	100	7.6	0.39	n/a	61	30.4	0.9	0	0	0.00	26	8	< 1	9	62	26	15	4.9	< 0.3
C-D	0-15	2	0-90	300	7.3	2.20	n/a	18	0.8	0.3	5978	616	0.32	3963	18	187	205	5995	4150	4682	21.4	221
C-D	15-30	2	0-90	300	7.8	0.80	n/a	21	3.4	0.4	4741	489	0.25	1828	189	1	191	4762	1830	1700	176	1.3
C-D	30-45	2	0-90	300	7.9	0.28	n/a	38	11.2	0.7	0	0	0.00	196	52	1	53	38	197	114	30.2	0.6
C-D	45-60	2	0-90	300	7.6	0.26	n/a	42	0.8	0.8	0	0	0.00	31	8	< 1	9	43	31	17	4.8	< 0.3
C-D	60-75	2	0-90	300	7.6	0.30	n/a	43	19.4	0.8	0	0	0.00	34	7	< 1	8	44	34	17	3.6	< 0.3
C-D	75-90	2	0-90	300	7.6	0.47	n/a	69	34.6	1.0	0	0	0.00	40	< 7	< 1	< 7	70	40	21	< 3.5	< 0.3
C-E	0-15	2	0-90	300	7.0	2.80	n/a	18	0.8	0.3	5978	616	0.32	4475	8	280	288	5995	4756	5287	9.4	331
C-E	15-30	2	0-90	300	7.6	0.78	n/a	21	3.4	0.4	4741	489	0.25	1260	139	33	172	4762	1293	1171	129	31.1
C-E	30-45	2	0-90	300	7.7	0.36	n/a	38	11.2	0.7	0	0	0.00	37	53	< 1	54	38	37	22	31	< 0.3
C-E	45-60	2	0-90	300	7.6	0.28	n/a	42	0.8	0.8	0	0	0.00	25	8	< 1	8	43	25	14	4.4	< 0.3
C-E	60-75	2	0-90	300	7.6	0.34	n/a	43	19.4	0.8	0	0	0.00	48	< 7	< 1	< 8	44	48	24	< 3.5	< 0.3
C-E	75-90	2	0-90	300	7.6	0.42	n/a	69	34.6	1.0	0	0	0.00	39	< 7	< 1	< 7	70	39	20	< 3.5	< 0.3

All samples were analyzed in the BIOE Laboratory.

LEACHING EXPERIMENT - RUN 1 - LABORATORY DATA - NITROGEN, pH, EC, LOI

								Background Nitrogen in Tailings			Nitrogen added with Biosolids			Nitrogen at the End of the Run				Total N	Total N	Nitrogen Concentration at the End of the Run		
Col.:	Depth: (cm)	Tailings from Site:	Column Length: (cm)	Appl. Rate: (dt/ha)	1:2 pH:	1:2 EC: (dS/m)	Loss on Ignition: (@450°C)	TKN Backg. (kg N/ ha)	NH4-N Backg. (kg N/ ha)	NO3-N Backg. (kg N/ ha)	TKN added: (kg N/ ha)	NH4-N added: (kg N/ ha)	NO3-N added: (kg N/ ha)	TKN at End (kg N/ ha)	NH4-N at End (kg N/ ha)	NO3-N at End (kg N/ ha)	Mineral Nitrogen at End (kg N/ ha)	at Start of Run (kg N/ ha)	at End of Run (kg N/ ha)	TKN: (mg N/ kg)	NH4-N: (mg N/ kg)	NO3-N: (mg N/ kg)
C-F	0-15	2	0-45	0	7.6	0.15	n/a	31	1.6	0.5	0	0	0.00	27	5	< 0.3	6	31	27	23	4.6	< 0.3
C-F	15-30	2	0-45	0	7.6	0.16	n/a	22	7.7	0.6	0	0	0.00	25	5	< 0.3	5	22	25	22	3.9	< 0.3
C-F	30-45	2	0-45	0	7.6	0.19	n/a	27	6.9	0.4	0	0	0.00	23	< 4	< 0.3	< 4	27	23	20	< 3.5	< 0.3
C-G	0-15	2	0-45	30	7.4	0.40	n/a	31	1.6	0.5	1072	110	0.06	627	10	35	45	1104	661	523	8.2	29.3
C-G	15-30	2	0-45	30	7.5	0.28	n/a	22	7.7	0.6	0	0	0.00	27	9	8	17	22	36	24	7.9	7.3
C-G	30-45	2	0-45	30	7.6	0.24	n/a	27	6.9	0.4	0	0	0.00	32	< 4	1	5	27	33	28	< 3.5	0.8
C-H	0-15	2	0-45	100	7.2	1.00	n/a	28	1.4	0.4	3227	333	0.17	3016	4	112	116	3256	3128	2635	3.6	98
C-H	15-30	2	0-45	100	7.4	0.34	n/a	24	7.8	0.6	346	36	0.02	314	4	24	28	371	338	249	3.3	19.4
C-H	30-45	2	0-45	100	7.5	0.37	n/a	27	6.9	0.4	0	0	0.00	28	< 4	9	13	27	37	24	< 3.5	7.9
C-I	0-15	2	0-45	300	7.0	1.40	n/a	18	0.8	0.3	5978	616	0.32	3277	11	130	141	5995	3407	3872	13.1	153
C-I	15-30	2	0-45	300	7.3	0.62	n/a	21	3.4	0.4	4741	489	0.25	1768	35	1	36	4762	1769	1644	32.4	1.3
C-I	30-45	2	0-45	300	7.5	0.51	n/a	38	11.2	0.7	0	0	0.00	137	53	4	57	38	141	80	31	2.3
C-J	0-15	2	0-60	0	7.4	0.17	n/a	31	1.6	0.5	0	0	0.00	31	< 4	< 0.3	< 4	31	31	29	< 3.5	< 0.3
C-J	15-30	2	0-60	0	7.4	0.17	n/a	22	7.7	0.6	0	0	0.00	24	< 4	< 0.3	< 4	22	24	24	< 3.5	< 0.3
C-J	30-45	2	0-60	0	7.5	0.17	n/a	27	6.9	0.4	0	0	0.00	23	< 4	< 0.3	< 4	27	23	20	< 3.5	< 0.3
C-J	45-60	2	0-60	0	7.2	0.19	n/a	40	0.1	0.7	0	0	0.00	34	< 6	< 0.3	< 6	40	34	20	< 3.5	< 0.3
C-K	0-15	2	0-60	30	7.3	0.34	n/a	31	1.6	0.5	1072	110	0.06	584	< 4	4	8	1104	588	488	< 3.5	3
C-K	15-30	2	0-60	30	6.9	0.24	n/a	22	7.7	0.6	0	0	0.00	44	< 4	2	6	22	47	39	< 3.5	1.9
C-K	30-45	2	0-60	30	7.0	0.22	n/a	27	6.9	0.4	0	0	0.00	27	< 4	0.4	4	27	28	24	< 3.5	0.4
C-K	45-60	2	0-60	30	7.0	0.20	n/a	40	0.1	0.7	0	0	0.00	27	< 6	< 0.5	< 6	40	27	16	< 3.5	< 0.3
C-L	0-15	2	0-60	100	7.1	1.20	n/a	28	1.4	0.4	3227	333	0.17	2356	5	165	170	3256	2521	2059	4.6	144
C-L	15-30	2	0-60	100	7.3	0.36	n/a	24	7.8	0.6	346	36	0.02	59	8	18	26	371	76	47	6.7	14
C-L	30-45	2	0-60	100	7.3	0.32	n/a	27	6.9	0.4	0	0	0.00	20	< 4	2	5	27	21	17	< 3.5	1.3
C-L	45-60	2	0-60	100	7.4	0.30	n/a	40	0.1	0.7	0	0	0.00	33	< 6	< 0.5	< 6	40	33	19	< 3.5	< 0.3
C-M	0-15	2	0-60	300	6.8	2.00	n/a	18	0.8	0.3	5978	616	0.32	4712	6	247	252	5995	4959	5567	7	292
C-M	15-30	2	0-60	300	7.3	0.67	n/a	21	3.4	0.4	4741	489	0.25	1378	12	20	32	4762	1397	1281	11.5	18.4
C-M	30-45	2	0-60	300	7.6	0.54	n/a	38	11.2	0.7	0	0	0.00	71	29	2	32	38	74	41	17.2	1.4
C-M	45-60	2	0-60	300	7.3	0.69	n/a	42	0.8	0.8	0	0	0.00	35	< 6	< 1	< 6	43	35	20	< 3.5	< 0.3

All samples were analyzed in the BIOE Laboratory.

LEACHING EXPERIM. - RUN 1 - NITROGEN, pH, EC - LONG FORM OF DATA ANALYSIS

Class Level Information

Class	Levels	Values			
Data for 0-45 cm Layers:					
APPL	4	_ 0 dt/ha	_ 30 dt/ha	_100 dt/ha	_300 dt/ha
LENGTH	3	_0-45 cm Col.		_0-60 cm Col.	_0-90 cm Col.
Number of observations in data set = 26				(DF for Error = 14)	
Data for 45-60 cm Layer:					
APPL	4	_ 0 dt/ha	_ 30 dt/ha	_100 dt/ha	_300 dt/ha
LENGTH	2	_0-60 cm Col.		_0-90 cm Col.	
Number of observations in data set = 18				(DF for Error = 10)	
Data for 60-90 cm Layers:					
APPL	4	_ 0 dt/ha	_ 30 dt/ha	_100 dt/ha	_300 dt/ha
LENGTH	1	_0-90 cm Col.			
Number of observations in data set = 10				(DF for Error = 6)	

Notes:
All samples were analyzed in the BIOE Lab.
The factorial model y=LENGTH|APPL and the Duncan multiple range test at the 0.05 level of probability was used to determine significantly different means.
'R-Square' refers to the R^2 of the factorial model in the SAS procedure GLM.
'Std. Dev. ' refers to the sample standard deviation.
'C.V.' refers to the coefficient of variation in percent.
'N' refers to the number of samples for average calculations.
Means preceded by different letters are significantly different.
In the analysis, if the concentration measured was below the detection limit, half the concentration of the detection limit was used for that element.

0-15 cm Layer:

		R-Square:	C.V.:	Std. Dev.:	Mean:
1:2 pH		0.468	3	0.2	7.3
1:2 EC	**(dS/m)**	APPL sig.			
TKN	**(mg/kg)**	APPL sig.			
NH4-N	**(mg/kg)**	0.331	305	125.6	41.2
NO3-N	**(mg/kg)**	APPL sig.			
NO3-N + NH4-N	**(mg/kg)**	APPL sig,			

0-15 cm 1:2 EC (dS/m):

Duncan Grouping	Mean	N	APPL
A	2.1	8	_300 dt/ha
B	1.0	6	_100 dt/ha
C	0.4	6	_ 30 dt/ha
C	0.1	6	_ 0 dt/ha

0-15 cm TKN (mg/kg):

Duncan Grouping	Mean	N	APPL
A	5502	8	_300 dt/ha
B	1917	6	_100 dt/ha
C	490	6	_ 30 dt/ha
C	22	6	_ 0 dt/ha

0-15 cm NO3-N (mg/kg):

Duncan Grouping	Mean	N	APPL
A	211	8	_300 dt/ha
A	139	6	_100 dt/ha
B	38	6	_ 30 dt/ha
B	0.2	6	_ 0 dt/ha

0-15 cm NO3-N + NH4-N (mg/kg):

Duncan Grouping		Mean	N	APPL
A		328	8	_300 dt/ha
B		149	6	_100 dt/ha
C	B	48	6	_ 30 dt/ha
C		4	6	_ 0 dt/ha

LEACHING EXPERIM. - RUN 1 - NITROGEN, pH, EC - LONG FORM OF DATA ANALYSIS

15-30 cm Layer:

		R-Square:	C.V.:	Std. Dev.:	Mean:
1:2 pH		0.429	3	0.2	7.5
1:2 EC	**(dS/m)**	APPL sig.			
TKN	**(mg/kg)**	APPL sig.			
NH4-N	**(mg/kg)**	LENGTH sig.			
NO3-N	**(mg/kg)**	0.572	97	14.2	14.6
NO3-N + NH4-N	**(mg/kg)**	APPL sig.			

15-30 cm 1:2 EC (dS/m):

Duncan Grouping	Mean	N	APPL
A	0.8	8	_300 dt/ha
B	0.3	6	_100 dt/ha
C	0.2	6	_ 30 dt/ha
C	0.2	6	_ 0 dt/ha

15-30 cm TKN (mg/kg):

Duncan Grouping	Mean	N	APPL
A	2243	8	_300 dt/ha
B	250	6	_100 dt/ha
B	45	6	_ 30 dt/ha
B	21	6	_ 0 dt/ha

15-30 cm NH4-N (mg/kg):

Duncan Grouping	Mean	N	LENGTH
A	78	10	_0-90 cm Col.
B	14	8	_0-60 cm Col.
B	13	8	_0-45 cm Col.

15-30 cm NO3-N + NH4-N (mg/kg):

Duncan Grouping		Mean	N	APPL
A		107	8	_300 dt/ha
B	A	61	6	_100 dt/ha
B	C	22	6	_ 30 dt/ha
C		4	6	_ 0 dt/ha

30-45 cm Layer:

		R-Square:	C.V.:	Std. Dev.:	Mean:
1:2 pH		0.578	2	0.2	7.6
1:2 EC	**(dS/m)**	APPL sig.			
TKN	**(mg/kg)**	0.626	79	32.9	41.7
NH4-N	**(mg/kg)**	0.420	216	31.5	14.6
NO3-N	**(mg/kg)**	APPL and LENGTH sig.			
NO3-N + NH4-N	**(mg/kg)**	0.417	204	31.6	15.5

30-45 cm 1:2 EC (dS/m):

Duncan Grouping	Mean	N	APPL
A	0.4	8	_300 dt/ha
B	0.3	6	_100 dt/ha
C	0.2	6	_ 30 dt/ha
C	0.2	6	_ 0 dt/ha

30-45 cm NO3-N (mg/kg):

Duncan Grouping	Mean	N	APPL
A	2.3	6	_100 dt/ha
B	0.8	8	_300 dt/ha
B	0.4	6	_ 30 dt/ha
B	0.2	6	_ 0 dt/ha

Duncan Grouping	Mean	N	LENGTH
A	1.9	8	_0-45 cm Col.
B	0.5	8	_0-60 cm Col.
B	0.4	10	_0-90 cm Col.

LEACHING EXPERIM. - RUN 1 - NITROGEN, pH, EC - LONG FORM OF DATA ANALYSIS

45-60 cm Layer:

		R-Square:	C.V.:	Std. Dev.:	Mean:
1:2 pH		0.149	3	0.3	7.5
1:2 EC	**(dS/m)**	0.602	36	0.1	0.3
TKN	**(mg/kg)**	0.162	26	5.0	19.5
NH4-N	**(mg/kg)**	0.333	78	2.3	3.0
NO3-N	**(mg/kg)**	0.000			0.2
NO3-N + NH4-N	**(mg/kg)**	0.333	74	2.3	3.1

60-75 cm Layer:

		R-Square:	C.V.:	Std. Dev.:	Mean:
1:2 pH		0.676	0.9	0.1	7.6
1:2 EC	**(dS/m)**	0.194	17.4	0.1	0.3
TKN	**(mg/kg)**	0.082	36.9	8.9	24.1
NH4-N	**(mg/kg)**	0.650	45.9	1.7	3.6
NO3-N	**(mg/kg)**	0.000			0.2
NO3-N + NH4-N	**(mg/kg)**	0.650	44.0	1.7	3.8

75-90 cm Layer:

		R-Square:	C.V.:	Std. Dev.:	Mean:
1:2 pH		0.380	1.5	0.1	7.6
1:2 EC	**(dS/m)**	0.015	12.6	0.1	0.4
TKN	**(mg/kg)**	0.131	23.8	5.2	21.9
NH4-N	**(mg/kg)**	APPL sig.			
NO3-N	**(mg/kg)**	0.000			0.2
NO3-N + NH4-N	**(mg/kg)**	APPL sig.			

75-90 cm NH4-N (mg/kg):

Duncan Grouping	Mean	N	APPL
A	6.4	2	_ 0 dt/ha
B	3.3	2	_100 dt/ha
B	3.3	2	_ 30 dt/ha
B	1.8	4	_300 dt/ha

75-90 cm NO3-N + NH4-N (mg/kg):

Duncan Grouping	Mean	N	APPL
A	6.5	2	_ 0 dt/ha
B	3.5	2	_100 dt/ha
B	3.4	2	_ 30 dt/ha
B	1.9	4	_300 dt/ha

APPENDIX E

Leaching Run 2 - Soil Nitrogen, pH, and EC

LEACHING EXP. - RUN 2 (COLUMNS) - NITROGEN BALANCE IN THE 0-45 cm LAYER

Class Level Information

Class	Levels	Values			
LENGTH	3	_0-45 cm Col.		_0-60 cm Col.	_0-90 cm Col.
APPL	4	_ 0 dt/ha	_ 30 dt/ha	_100 dt/ha	_300 dt/ha

Number of observations in data set = 26 (DF for Error = 14)

Notes:
All samples were analyzed in the BIOE Lab.
The factorial model with parameters LENGTH (column length) and APPL (application rate) was run on the data.
The Duncan multiple range test at the 0.05 level of probability was used to determine significantly different means. This test controls the type I comparisonwise error rate, not the experimentwise error rate.
'N' refers to the number of samples for average calculations.
Means preceded by different letters are significantly different.

Start Soil N (mg N/column):

Duncan Grouping	Mean	N	APPL
A	19507	8	_300 dt/ha
B	6643	6	_100 dt/ha
C	2135	6	_ 30 dt/ha
D	233	6	_ 0 dt/ha

End Soil N (mg N/column):

Duncan Grouping	Mean	N	APPL
A	13634	8	_300 dt/ha
B	6107	6	_100 dt/ha
C	2001	6	_ 30 dt/ha
D	175	6	_ 0 dt/ha

Soil N lost (mg N/column):

Duncan Grouping	Mean	N	APPL
A	5874	8	_300 dt/ha
B	536	6	_100 dt/ha
B	134	6	_ 30 dt/ha
B	57	6	_ 0 dt/ha

LEACHING EXP. - RUN 2 (POTS) - NITROGEN BALANCE IN THE 0-15 cm LAYER

Class Level Information

Class	Levels	Values			
APPL	4	_ 0 dt/ha	_ 30 dt/ha	_100 dt/ha	_300 dt/ha

Number of observations in data set = 10 (DF for Error = 6)

Notes:
All samples were analyzed in the BIOE Lab.
The main effect model with parameter APPL (application rate) was applied to the data.
The Duncan multiple range test at the 0.05 level of probability was used to determine significantly different means. This test controls the type I comparisonwise error rate, not the experimentwise error rate.
'N' refers to the number of samples for average calculations.
Means preceded by different letters are significantly different.

Start Soil N (mg N/column):

Duncan Grouping		Mean	N	APPL
A		19349	3	_300 dt/ha
B		6494	3	_100 dt/ha
C		1995	3	_ 30 dt/ha
D		66	1	_ 0 dt/ha

End Soil N (mg N/column):

Duncan Grouping		Mean	N	APPL
A		12711	3	_300 dt/ha
B		4337	3	_100 dt/ha
C	B	1408	3	_ 30 dt/ha
C		66	1	_ 0 dt/ha

Soil N lost (mg N/column):

Duncan Grouping		Mean	N	APPL
A		6638	3	_300 dt/ha
B		2157	3	_100 dt/ha
B		587	3	_ 30 dt/ha
B		0	1	_ 0 dt/ha

LEACHING EXPERIMENT - RUN 2 - NITROGEN, pH, EC, LOI - OVERVIEW

Class	**Levels**	**Values**			
Data for Columns (0-15, 15-30, 30-45 cm Layers):					
APPL	4	_ 0 dt/ha	_ 30 dt/ha	_100 dt/ha	_300 dt/ha
LENGTH	3	_0-45 cm Col.		_0-60 cm Col.	_0-90 cm Col.

Number of observations for LOI in the 0-15 cm Layer = 21 (DF for Error = 9)
Number of observations for LOI in the 15-30 cm Layer = 19 (DF for Error = 7)
Number of observations for all other parameters = 26 (DF for Error = 14)

Data for Columns (45-60 cm Layer):					
APPL	4	_ 0 dt/ha	_ 30 dt/ha	_100 dt/ha	_300 dt/ha
LENGTH	2	_0-60 cm Col.		_0-90 cm Col.	

Number of observations in data set = 18 (DF for Error = 10)

Data for Columns (60-75 and 75-90 cm Layers):					
APPL	4	_ 0 dt/ha	_ 30 dt/ha	_100 dt/ha	_300 dt/ha
LENGTH	1	_0-90 cm Col.			

Number of observations in data set = 10 (DF for Error = 6)

Data for Pot Trials (0-15 cm Layer):					
APPL	4	_ 0 dt/ha	_ 30 dt/ha	_100 dt/ha	_300 dt/ha

Number of observations in data set = 10 (DF for Error = 6)

LEACHING RUN 2							
DEPTH:		**1:2 pH**	**1:2 EC (dS/m)**	**Loss on Ignition (%)**	**TKN (mg/kg)**	**NH4-N (mg/kg)**	**NO3-N (mg/kg)**
0 - 15 cm	**Mean**	7.3	2.0	APPL sig.	APPL sig.	90.4	APPL sig.
	Std. Dev.	0.2	1.3			87.2	
15 - 30 cm	**Mean**	7.5	1.3	APPL sig.	APPL sig.	APPL sig.	102.1
	Std. Dev.	0.2	1.0				143.6
30 - 45 cm	**Mean**	APPL sig.	0.6	n/a	APPL sig.	APPL sig.	25.7
	Std. Dev.		0.3				40.2
45 - 60 cm	**Mean**	7.5	0.5	n/a	28.6	8.2	0.7
	Std. Dev.	0.1	0.3		21.1	18.2	1.0
60 - 75 cm	**Mean**	7.4	0.6	n/a	20.0	2.6	0.4
	Std. Dev.	0.1	0.3		11.2	2.4	0.5
75 - 90 cm	**Mean**	7.4	0.7	n/a	13.6	1.7	0.1
	Std. Dev.	0.1	0.5		8.3	1.2	0.0
Pot Trial	**Mean**	n/a	n/a	APPL sig.	APPL sig.	APPL sig.	APPL sig.

Notes:
All samples were analyzed in the BIOE Lab.
The factorial model y=LENGTH|APPL was used for the columns and the main effect model y=APPL was used in the data analysis for the pot trials.
The Duncan multiple range test at the 0.05 level of probability was used to determine significantly different means.
'Std. Dev. ' refers to the sample standard deviation.

LEACHING EXP. - RUN 2 - NITROGEN, pH, EC, LOI - SIG. PARAMETERS

Class **Levels** **Values**

Data for Columns (0-15, 15-30, 30-45 cm Layers):

APPL	4	_ 0 dt/ha	_ 30 dt/ha	_100 dt/ha	_300 dt/ha	
LENGTH	3	_0-45 cm Col.		_0-60 cm Col.		_0-90 cm Col.

Number of observations for LOI in the 0-15 cm Layer = 21 (DF for Error = 9)
Number of observations for LOI in the 15-30 cm Layer = 19 (DF for Error = 7)
Number of observations for all other parameters = 26 (DF for Error = 14)

Data for Columns (45-60 cm Layer):

APPL	4	_ 0 dt/ha	_ 30 dt/ha	_100 dt/ha	_300 dt/ha
LENGTH	2	_0-60 cm Col.		_0-90 cm Col.	

Number of observations in data set = 18 (DF for Error = 10)

Data for Columns (60-75 and 75-90 cm Layers):

APPL	4	_ 0 dt/ha	_ 30 dt/ha	_100 dt/ha	_300 dt/ha
LENGTH	1	_0-90 cm Col.			

Number of observations in data set = 10 (DF for Error = 6)

Data for Pot Trials (0-15 cm Layer):

APPL	4	_ 0 dt/ha	_ 30 dt/ha	_100 dt/ha	_300 dt/ha

Number of observations in data set = 10 (DF for Error = 6)

Notes:
All samples were analyzed in the BIOE Lab.
The factorial model y=LENGTH|APPL was used for the columns and the main effect model y=APPL was used for the pot trials.
The Duncan multiple range test at the 0.05 level of probability was used to determine significantly different means.
'N' refers to the number of samples for average calculations.
Means followed or preceded by different letters are significantly different.

Loss on Ignition

Depth / Appl.:	0 dt/ha	30 dt/ha	100 dt/ha	300 dt/ha
0 - 15 cm	1.2 d	2.5 c	5 b	11 a
15 - 30 cm	1 b	1.1 b	1.8 b	8.7 a
Pot Trial	0.7 d	2.4 c	5.8 b	11.2 a

TKN (mg/kg)

Depth / Appl.:	0 dt/ha	30 dt/ha	100 dt/ha	300 dt/ha
0 - 15 cm	52 d	725 c	2252 b	4791 a
15 - 30 cm	40 b	151 b	583 b	4401 a
30 - 45 cm	26 b	30 b	69 b	386 a
45 - 60 cm	avg. value:	29		
60 - 75 cm	avg. value:	20		
75 - 90 cm	avg. value:	13.6		
Pot Trial	27 c	516 c	1925 b	5008 a

NH4-N (mg/kg)

Depth / Appl.:	0 dt/ha	30 dt/ha	100 dt/ha	300 dt/ha
0 - 15 cm	avg. value:	90.4		
15 - 30 cm	1 c	46 c	255 b	723 a
30 - 45 cm	1 c	6 bc	39 b	251 a
45 - 60 cm	avg. value:	8.2		
60 - 75 cm	avg. value:	2.6		
75 - 90 cm	avg. value:	1.7		
Pot Trial	1 b	3.2 b	5 b	19.1 a

NO3-N (mg/kg)

Depth / Appl.:	0 dt/ha	30 dt/ha	100 dt/ha	300 dt/ha
0 - 15 cm	0.1 c	235 bc	702 ab	928 a
15 - 30 cm	avg. value:	102		
30 - 45 cm	avg. value:	25.7		
45 - 60 cm	avg. value:	0.7		
60 - 75 cm	avg. value:	0.4		
75 - 90 cm	avg. value:	0.1		
Pot Trial	9 c	247 b	295 b	615 a

30-45 cm 1:2 pH:

Duncan Grouping	Mean	N	APPL
a	7.8	8	_300 dt/ha
b	7.5	6	_100 dt/ha
c b	7.4	6	_ 30 dt/ha
c	7.3	6	_ 0 dt/ha

LEACHING EXPERIMENT - RUN 2 (COLUMNS) - LABORATORY DATA - NITROGEN, pH, EC, LOI

Col.:	Depth: (cm)	Tailings from Site:	Column Length: (cm)	Appl. Rate: (dt/ha)	1:2 pH:	1:2 EC: (dS/m)	Loss on Ignition: (@450°C)	Background Nitrogen in Tailings: TKN Backg. (kg N/ ha)	NH4-N Backg. (kg N/ ha)	NO3-N Backg. (kg N/ ha)	Nitrogen added with Biosolids: TKN added: (kg N/ ha)	NH4-N added: (kg N/ ha)	NO3-N added: (kg N/ ha)	Nitrogen at the End of the Run: TKN at End (kg N/ ha)	NH4-N at End (kg N/ ha)	NO3-N at End (kg N/ ha)	Mineral Nitrogen at End (kg N/ ha)	Total N at Start of Run (kg N/ ha)	Total N at End of Run (kg N/ ha)	Nitrogen Concentration at the End of the Run: TKN: (mg N/ kg)	NH4-N: (mg N/ kg)	NO3-N: (mg N/ kg)
C1	0-15	3	0-90	0	7.8	0.16	n/a	69	1.2	0.3	0	0	0.00	63	< 2	< 0.3	< 3	69	63	55	< 2	<0.25
C1	15-30	3	0-90	0	7.3	0.20	n/a	48	1.1	0.2	0	0	0.00	< 23	< 2	< 0.1	< 2	48	< 26	< 26	< 2	<0.14
C1	30-45	3	0-90	0	6.9	0.24	n/a	53	1.2	0.2	0	0	0.00	22	< 2	< 0.1	< 2	53	22	24	< 2	<0.14
C1	45-60	3	0-90	0	7.1	0.29	n/a	50	2.5	0.4	0	0	0.00	10	< 3	< 0.2	< 3	51	10	7	< 2	<0.14
C1	60-75	3	0-90	0	7.3	0.47	n/a	66	2.9	0.5	0	0	0.00	38	< 4	0.5	< 4	66	39	21	< 2	<0.14
C1	75-90	3	0-90	0	7.3	0.50	n/a	67	4.9	0.3	0	0	0.00	49	< 4	< 0.3	< 5	67	49	22	< 2	<0.14
C2	0-15	3	0-90	30	7.2	0.92	n/a	54	0.9	0.2	1257	145	0.04	584	38	115	153	1311	698	657	41.6	124
C2	15-30	3	0-90	30	7.3	0.49	n/a	61	1.4	0.3	0	0	0.00	264	31	402	432	61	663	243	26.1	343
C2	30-45	3	0-90	30	7.3	0.50	n/a	53	1.2	0.2	0	0	0.00	16	< 2	35	37	53	51	17	< 2	38
C2	45-60	3	0-90	30	7.5	0.30	n/a	50	2.5	0.4	0	0	0.00	< 15	< 3	3	6	51	3	< 10	< 2	2.1
C2	60-75	3	0-90	30	7.4	0.39	n/a	66	2.9	0.5	0	0	0.00	29	< 4	< 0.3	< 4	66	29	16	< 2	<0.14
C2	75-90	3	0-90	30	7.4	0.25	n/a	67	4.9	0.3	0	0	0.00	40	< 4	< 0.3	< 5	67	40	18	< 2	<0.14
C3	0-15	3	0-90	100	7.4	1.20	5.0	65	1.1	0.3	3927	453	0.12	2573	232	537	770	3992	3111	2211	200	461.6
C3	15-30	3	0-90	100	7.6	0.68	1.9	52	1.2	0.3	262	30	0.01	669	288	< 0.1	288	314	669	669	288	<0.14
C3	30-45	3	0-90	100	7.5	0.26	n/a	53	1.2	0.2	0	0	0.00	41	22	< 1	23	53	41	45	23	<1.53
C3	45-60	3	0-90	100	7.5	0.31	n/a	50	2.5	0.4	0	0	0.00	97	< 3	< 0.2	< 3	51	97	66	< 2	<0.14
C3	60-75	3	0-90	100	7.4	0.22	n/a	66	2.9	0.5	0	0	0.00	29	< 4	< 0.3	< 4	66	29	16	< 2	<0.14
C3	75-90	3	0-90	100	7.5	0.35	n/a	67	4.9	0.3	0	0	0.00	45	< 4	< 0.3	< 5	67	45	20	< 2	<0.14
C4	0-15	3	0-90	300	7.2	2.30	11.8	38	0.7	0.1	7008	810	0.22	4423	69	1330	1399	7047	5753	5501	86	1654
C4	15-30	3	0-90	300	7.8	1.10	6.4	34	0.8	0.1	5558	642	0.17	2796	578	0.1	578	5592	2796	3571	738	<0.14
C4	30-45	3	0-90	300	7.6	0.31	n/a	98	2.2	0.3	0	0	0.00	346	252	15	268	98	361	204	149	8.9
C4	45-60	3	0-90	300	7.5	0.26	n/a	65	3.1	0.5	0	0	0.00	50	< 4	< 0.3	< 4	65	50	26	< 2	<0.14
C4	60-75	3	0-90	300	7.4	0.27	n/a	64	2.8	0.5	0	0	0.00	13	< 4	< 0.3	< 4	65	13	7	< 2	<0.14
C4	75-90	3	0-90	300	7.4	0.46	n/a	55	4.0	0.3	0	0	0.00	< 9	< 4	< 0.3	< 4	55	0	< 5	< 2	<0.14
C5	0-15	3	0-90	300	7.1	2.25	11.5	38	0.7	0.1	7008	810	0.22	3796	36	291	327	7047	4087	4722	44.7	361.6
C5	15-30	3	0-90	300	7.6	2.20	8.2	50	0.8	0.1	5558	642	0.17	3336	517	< 0.1	517	5609	3336	4259	660	<0.14
C5	30-45	3	0-90	300	7.8	0.60	n/a	125	2.2	0.3	0	0	0.00	655	483	2	485	125	656	386	285	1.01
C5	45-60	3	0-90	300	7.5	0.33	n/a	65	3.1	0.5	0	0	0.00	26	< 4	< 0.3	< 4	65	26	14	< 2	<0.14
C5	60-75	3	0-90	300	7.6	0.30	n/a	110	2.8	0.5	0	0	0.00	11	< 4	< 0.3	< 4	111	11	6	< 2	<0.14
C5	75-90	3	0-90	300	7.6	0.28	n/a	76	4.0	0.3	0	0	0.00	34	< 4	< 0.3	< 4	76	34	19	< 2	<0.14

All samples were analyzed in the BIOE Laboratory.

LEACHING EXPERIMENT - RUN 2 (COLUMNS) - LABORATORY DATA - NITROGEN, pH, EC, LOI

Col.:	Depth: (cm)	Tailings from Site:	Colunm Length: (cm)	Appl. Rate: (dt/ha)	1:2 pH:	1:2 EC: (dS/m)	Loss on Ignition: (@450°C)	Background Nitrogen in Tailings: TKN Backg. (kg N/ ha)	NH4-N Backg. (kg N/ ha)	NO3-N Backg. (kg N/ ha)	Nitrogen added with Biosolids: TKN added: (kg N/ ha)	NH4-N added: (kg N/ ha)	NO3-N added: (kg N/ ha)	Nitrogen at the End of the Run: TKN at End (kg N/ ha)	NH4-N at End (kg N/ ha)	NO3-N at End (kg N/ ha)	Mineral Nitrogen at End (kg N/ ha)	Total N at Start of Run (kg N/ ha)	Total N at End of Run (kg N/ ha)	Nitrogen Concentration at the End of the Run: TKN: (mg N/ kg)	NH4-N: (mg N/ kg)	NO3-N: (mg N/ kg)
C6	0-15	3	0-45	0	7.5	0.14	n/a	69	1.2	0.3	0	0	0.00	47	< 2	0.3	< 3	69	47	41	< 2	0.3
C6	15-30	3	0-45	0	7.4	0.22	n/a	48	1.1	0.2	0	0	0.00	70	< 2	< 0.1	< 2	48	70	77	< 2	<0.14
C6	30-45	3	0-45	0	7.6	0.20	n/a	53	1.2	0.2	0	0	0.00	51	< 2	< 0.1	< 2	53	51	55	< 2	<0.14
C7	0-15	3	0-45	30	7.3	1.00	n/a	69	1.2	0.3	1257	145	0.04	710	24	163	187	1326	873	606	20.4	139.4
C7	15-30	3	0-45	30	7.5	0.46	n/a	48	1.1	0.2	0	0	0.00	69	62	143	205	48	212	75	67.8	155.3
C7	30-45	3	0-45	30	7.6	0.32	n/a	53	1.2	0.2	0	0	0.00	38	9	43	52	53	82	42	9.4	46.7
C8	0-15	3	0-45	100	7.5	1.00	4.7	65	1.1	0.3	3927	453	0.12	2333	232	1558	1789	3992	3890	2004	199	1338
C8	15-30	3	0-45	100	7.8	0.44	0.9	52	1.2	0.3	262	30	0.01	220	239	100	340	314	320	220	240	100
C8	30-45	3	0-45	100	7.6	0.28	n/a	53	1.2	0.2	0	0	0.00	57	31	11	41	53	67	61	33.3	11.6
C9	0-15	3	0-45	300	7.2	2.00	10.2	38	0.7	0.1	7008	810	0.22	3455	16	200	216	7047	3655	4298	19.8	248.8
C9	15-30	3	0-45	300	7.8	1.00	10.8	50	0.8	0.1	5558	642	0.17	4784	602	< 0.1	602	5609	4784	6109	769	<0.14
C9	30-45	3	0-45	300	8.0	0.40	n/a	125	2.2	0.3	0	0	0.00	832	385	32	417	125	864	491	227	18.7
C10	0-15	3	0-60	0	7.7	0.15	n/a	69	1.2	0.3	0	0	0.00	56	< 2	< 0.3	< 3	69	56	49	< 2	<0.21
C10	15-30	3	0-60	0	7.7	0.17	n/a	48	1.1	0.2	0	0	0.00	49	< 5	< 0.1	< 5	48	49	53	< 2	<0.14
C10	30-45	3	0-60	0	7.6	0.24	n/a	53	1.2	0.2	0	0	0.00	12	< 5	1	6	53	13	13	< 2	0.6
C10	45-60	3	0-60	0	7.6	0.30	n/a	50	2.5	0.4	0	0	0.00	25	< 3	1	4	51	26	17	< 2	0.6
C11	0-15	3	0-60	30	7.5	0.52	2.2	69	1.2	0.3	1257	145	0.04	973	< 25	181	206	1326	1153	830	< 22	154.4
C11	15-30	3	0-60	30	7.7	0.30	n/a	48	1.1	0.2	0	0	0.00	132	44	< 0.1	44	48	132	143	47.7	<0.14
C11	30-45	3	0-60	30	7.6	0.23	n/a	53	1.2	0.2	0	0	0.00	30	5	2	7	53	31	32	5.7	1.7
C11	45-60	3	0-60	30	7.6	0.29	n/a	50	2.5	0.4	0	0	0.00	29	< 3	< 0.2	< 3	51	29	19	< 2	<0.14
C12	0-15	3	0-60	100	7.5	1.00	4.7	65	1.1	0.3	3927	453	0.12	2622	262	785	1048	3992	3408	2253	225	675
C12	15-30	3	0-60	100	7.9	0.58	1.0	52	1.2	0.3	262	30	0.01	337	245	< 0.1	245	314	337	337	245	<0.14
C12	30-45	3	0-60	100	7.7	0.25	n/a	53	1.2	0.2	0	0	0.00	62	26	5	31	53	67	68	28.2	5.4
C12	45-60	3	0-60	100	7.6	0.32	n/a	50	2.5	0.4	0	0	0.00	31	< 3	1	4	51	32	21	< 2	0.8
C13	0-15	3	0-60	300	7.4	1.20	10.0	38	0.7	0.1	7008	810	0.22	3938	215	750	965	7047	4689	4898	267	933
C13	15-30	3	0-60	300	8.0	0.70	10.4	50	0.8	0.1	5558	642	0.17	3723	885	< 0.1	885	5609	3723	4753	1130	<0.14
C13	30-45	3	0-60	300	8.0	0.40	n/a	125	2.2	0.3	0	0	0.00	693	506	< 0.3	506	125	693	409	298	<0.14
C13	45-60	3	0-60	300	7.5	0.26	n/a	50	2.5	0.4	0	0	0.00	55	3	< 0.2	4	51	55	37	2.3	<0.14

All samples were analyzed in the BIOE Laboratory.

LEACHING EXPERIMENT - RUN 2 (COLUMNS) - LABORATORY DATA - NITROGEN, pH, EC, LOI

Col.:	Depth: (cm)	Tailings from Site:	Column Length: (cm)	Appl. Rate: (dt/ha)	1:2 pH:	1:2 EC: (dS/m)	Loss on Ignition: (@450°C)	Background Nitrogen in Tailings: TKN Backg. (kg N/ ha)	NH4-N Backg. (kg N/ ha)	NO3-N Backg. (kg N/ ha)	Nitrogen added with Biosolids: TKN added: (kg N/ ha)	NH4-N added: (kg N/ ha)	NO3-N added: (kg N/ ha)	Nitrogen at the End of the Run: TKN at End (kg N/ ha)	NH4-N at End (kg N/ ha)	NO3-N at End (kg N/ ha)	Mineral Nitrogen at End (kg N/ ha)	Total N at Start of Run (kg N/ ha)	Total N at End of Run (kg N/ ha)	Nitrogen Concentration at the End of the Run: TKN: (mg N/ kg)	NH4-N: (mg N/ kg)	NO3-N: (mg N/ kg)
C-A	0-15	4	0-90	0	7.2	2.40	1.0	83	1.2	1.9	0	0	0.00	66	< 2	< 0.2	< 3	84	66	55	< 2	<0.14
C-A	15-30	4	0-90	0	7.3	1.40	0.9	18	0.8	0.3	0	0	0.00	25	< 2	< 0.1	< 2	19	25	33	< 2	<0.14
C-A	30-45	4	0-90	0	7.3	0.73	1.1	29	0.8	0.2	0	0	0.00	15	< 2	< 0.1	< 2	30	15	18	< 2	<0.14
C-A	45-60	4	0-90	0	7.4	0.68	n/a	44	2.1	0.3	0	0	0.00	28	< 2	< 0.2	< 3	45	28	23	< 2	<0.14
C-A	60-75	4	0-90	0	7.4	0.73	n/a	49	3.1	0.5	0	0	0.00	35	5	< 0.3	6	51	35	19	2.9	<0.14
C-A	75-90	4	0-90	0	7.4	1.30	n/a	40	3.6	0.4	0	0	0.00	32	4	< 0.3	5	42	32	19	2.5	<0.14
C-B	0-15	4	0-90	30	7.0	2.40	2.5	51	0.7	1.2	1257	145	0.04	549	18	431	449	1309	979	746	24.2	565
C-B	15-30	4	0-90	30	7.5	1.00	1.1	16	0.7	0.3	0	0	0.00	65	26	216	241	16	280	121	36.8	311
C-B	30-45	4	0-90	30	7.3	0.85	n/a	27	0.8	0.1	0	0	0.00	22	6	62	68	27	84	27	7.2	77.4
C-B	45-60	4	0-90	30	7.4	0.85	1.0	44	2.1	0.3	0	0	0.00	15	< 2	4	7	44	19	12	< 2	3.5
C-B	60-75	4	0-90	30	7.3	0.85	n/a	49	3.1	0.5	0	0	0.00	82	6	< 0.3	6	50	82	43	3	<0.14
C-B	75-90	4	0-90	30	7.3	1.00	n/a	40	3.6	0.4	0	0	0.00	< 12	< 3	< 0.3	< 4	40	0	< 7	< 2	<0.14
C-C	0-15	4	0-90	100	7.2	3.00	5.4	62	0.9	1.4	3273	378	0.10	2619	164	749	913	3337	3368	2707	170	774
C-C	15-30	4	0-90	100	7.3	1.50	1.4	21	0.9	0.3	916	106	0.03	468	233	141	374	938	609	498	248	150
C-C	30-45	4	0-90	100	7.5	0.59	n/a	34	1.0	0.2	0	0	0.00	70	31	56	87	35	126	69	31	55.1
C-C	45-60	4	0-90	100	7.4	0.62	n/a	44	2.1	0.3	0	0	0.00	23	6	5	11	44	27	19	5.1	3.8
C-C	60-75	4	0-90	100	7.4	0.73	n/a	49	3.1	0.5	0	0	0.00	40	5	1	6	50	41	21	2.7	0.6
C-C	75-90	4	0-90	100	7.5	1.00	n/a	40	3.6	0.4	0	0	0.00	< 12	< 3	< 0.3	< 4	40	0	< 6	< 2	<0.14
C-D	0-15	4	0-90	300	6.9	4.20	11.4	46	0.7	1.0	6982	806	0.22	4074	11	733	744	7029	4805	4920	13.9	885
C-D	15-30	4	0-90	300	7.2	4.20	9.2	16	0.7	0.3	5585	645	0.18	3511	434	213	646	5602	3724	4211	520	255
C-D	30-45	4	0-90	300	7.7	0.94	n/a	50	1.4	0.3	0	0	0.00	588	370	64	434	50	653	403	254	44
C-D	45-60	4	0-90	300	7.4	0.63	n/a	53	2.5	0.4	0	0	0.00	82	25	< 0.2	25	54	82	56	17.2	<0.14
C-D	60-75	4	0-90	300	7.4	0.78	n/a	42	2.7	0.4	0	0	0.00	37	10	2	12	42	38	23	6.4	1.2
C-D	75-90	4	0-90	300	7.3	1.00	n/a	40	3.6	0.4	0	0	0.00	20	7	< 0.3	7	40	20	12	4	<0.14
C-E	0-15	4	0-90	300	7.2	3.20	11.0	46	0.7	1.0	6982	806	0.22	3624	307	1678	1986	7029	5303	4377	371	2027
C-E	15-30	4	0-90	300	7.5	3.00	8.6	16	0.7	0.3	5585	645	0.18	3507	615	25	640	5602	3532	4206	738	29.4
C-E	30-45	4	0-90	300	7.7	0.90	n/a	50	1.4	0.3	0	0	0.00	551	367	13	380	50	564	377	251	9
C-E	45-60	4	0-90	300	7.4	0.87	n/a	53	2.5	0.4	0	0	0.00	32	10	< 0.2	11	54	32	22	7.1	<0.14
C-E	60-75	4	0-90	300	7.5	0.94	n/a	42	2.7	0.4	0	0	0.00	45	10	2	13	42	47	28	6.4	1.4
C-E	75-90	4	0-90	300	7.3	1.00	n/a	40	3.6	0.4	0	0	0.00	29	6	< 0.3	6	40	29	17	3.7	<0.14

All samples were analyzed in the BIOE Laboratory.

LEACHING EXPERIMENT - RUN 2 (COLUMNS) - LABORATORY DATA - NITROGEN, pH, EC, LOI

Col.:	Depth: (cm)	Tailings from Site:	Colunm Length: (cm)	Appl. Rate: (dt/ha)	1:2 pH:	1:2 EC: (dS/m)	Loss on Ignition: (@450°C)	Background Nitrogen in Tailings: TKN Backg. (kg N/ ha)	NH4-N Backg. (kg N/ ha)	NO3-N Backg. (kg N/ ha)	Nitrogen added with Biosolids: TKN added: (kg N/ ha)	NH4-N added: (kg N/ ha)	NO3-N added: (kg N/ ha)	Nitrogen at the End of the Run: TKN at End (kg N/ ha)	NH4-N at End (kg N/ ha)	NO3-N at End (kg N/ ha)	Mineral Nitrogen at End (kg N/ ha)	Total N at Start of Run (kg N/ ha)	Total N at End of Run (kg N/ ha)	Nitrogen Concentration at the End of the Run: TKN: (mg N/ kg)	NH4-N: (mg N/ kg)	NO3-N: (mg N/ kg)
C-F	0-15	4	0-45	0	7.4	2.40	1.5	83	1.2	1.9	0	0	0.00	80	5	< 0.2	5	84	80	71	4.2	<0.14
C-F	15-30	4	0-45	0	7.4	1.80	1.0	18	0.8	0.3	0	0	0.00	34	2	< 0.1	3	19	34	50	3.2	<0.14
C-F	30-45	4	0-45	0	7.2	0.82	n/a	29	0.8	0.2	0	0	0.00	16	< 2	< 0.1	< 2	30	16	19	< 2	<0.14
C-G	0-15	4	0-45	30	7.1	2.60	2.5	46	0.7	1.0	1257	145	0.04	485	8	152	160	1304	638	725	11.5	220
C-G	15-30	4	0-45	30	7.4	1.20	1.2	15	0.7	0.2	0	0	0.00	70	14	441	455	15	511	137	21.8	699
C-G	30-45	4	0-45	30	7.4	0.75	n/a	25	0.7	0.1	0	0	0.00	25	5	159	164	25	185	35	6.9	218
C-H	0-15	4	0-45	100	7.1	2.95	5.0	63	0.9	1.4	3273	378	0.10	2016	57	444	502	3337	2460	2017	57	444
C-H	15-30	4	0-45	100	7.3	1.75	2.8	19	0.8	0.3	916	106	0.03	980	149	421	570	936	1400	1172	178	504
C-H	30-45	4	0-45	100	7.4	0.70	n/a	24	0.7	0.1	0	0	0.00	40	34	74	108	23	115	58	48	106
C-I	0-15	4	0-45	300	7.2	3.95	10.8	48	0.7	1.1	7250	837	0.22	4078	66	425	491	7299	4503	4744	76.9	494.6
C-I	15-30	4	0-45	300	7.6	2.00	6.8	19	0.8	0.3	5317	614	0.16	3492	536	9	545	5336	3502	3718	569.8	9.9
C-I	30-45	4	0-45	300	7.7	0.92	n/a	44	1.3	0.3	0	0	0.00	393	277	8	286	45	401	297	210	6.3
C-J	0-15	4	0-60	0	7.3	2.40	1.0	83	1.2	1.9	0	0	0.00	46	3	< 0.2	4	84	46	39	2.9	<0.14
C-J	15-30	4	0-60	0	7.4	0.88	n/a	18	0.8	0.3	0	0	0.00	12	< 2	< 0.1	< 2	19	12	16	< 2	<0.14
C-J	30-45	4	0-60	0	7.4	0.60	n/a	29	0.8	0.2	0	0	0.00	21	< 2	< 0.1	< 2	30	21	24	< 2	<0.14
C-J	45-60	4	0-60	0	7.5	0.75	n/a	44	2.1	0.3	0	0	0.00	12	4	< 0.2	4	45	12	10	3.3	<0.14
C-K	0-15	4	0-60	30	7.4	2.50	2.6	70	1.0	1.6	1257	145	0.04	817	69	215	284	1329	1032	786	67	207
C-K	15-30	4	0-60	30	7.4	1.20	1.1	22	1.0	0.3	0	0	0.00	179	70	23	94	22	202	188	74	24
C-K	30-45	4	0-60	30	7.4	0.66	1.0	29	0.8	0.2	0	0	0.00	25	4	< 0.1	4	29	25	29	4.2	<0.14
C-K	45-60	4	0-60	30	7.4	0.96	n/a	44	2.1	0.3	0	0	0.00	46	21	< 0.2	21	44	46	38	17.6	<0.14
C-L	0-15	4	0-60	100	7.2	2.80	5.1	72	1.0	1.6	3273	378	0.10	2619	339	584	924	3347	3203	2320	301	518
C-L	15-30	4	0-60	100	7.4	2.00	2.5	21	0.9	0.3	916	106	0.03	564	309	37	345	938	601	604	330	39.2
C-L	30-45	4	0-60	100	7.5	0.68	n/a	29	0.8	0.2	0	0	0.00	96	62	11	73	29	107	112	72	12.9
C-L	45-60	4	0-60	100	7.5	0.82	n/a	44	2.1	0.3	0	0	0.00	26	8	< 0.2	8	44	26	22	6.4	<0.14
C-M	0-15	4	0-60	300	7.0	3.60	11.8	46	0.7	1.0	7008	810	0.22	4044	110	680	791	7056	4724	4866	133	818.9
C-M	15-30	4	0-60	300	7.5	2.80	9.2	15	0.7	0.2	5558	642	0.17	3337	501	26	527	5573	3363	4378	657	34.3
C-M	30-45	4	0-60	300	7.8	1.20	n/a	43	1.3	0.3	0	0	0.00	669	426	8	434	44	676	521	332	5.9
C-M	45-60	4	0-60	300	7.5	0.64	n/a	53	2.5	0.4	0	0	0.00	145	115	2	117	53	147	100	79.2	1.5

All samples were analyzed in the BIOE Laboratory.

LEACHING EXPERIMENT - RUN 2 (POT TRIAL) - LABORATORY DATA - NITROGEN, pH, EC, LOI

							Background Nitrogen in Tailings			Nitrogen added with Biosolids			Nitrogen at the End of the Run				Total N	Total N	Nitrogen Concentration at the End of the Run		
Pot:	Tailings from Site:	Colunm Length: (cm)	Appl. Rate: (dt/ha)	1:2 pH:	1:2 EC: (dS/m)	Loss on Ignition: (@450°C)	TKN Backg. (kg N/ ha)	NH4-N Backg. (kg N/ ha)	NO3-N Backg. (kg N/ ha)	TKN added: (kg N/ ha)	NH4-N added: (kg N/ ha)	NO3-N added: (kg N/ ha)	TKN at End (kg N/ ha)	NH4-N at End (kg N/ ha)	NO3-N at End (kg N/ ha)	Mineral Nitrogen at End (kg N/ ha)	at Start of Run (kg N/ ha)	at End of Run (kg N/ ha)	TKN: (mg N/ kg)	NH4-N: (mg N/ kg)	NO3-N: (mg N/ kg)
Pot 1	5	0-15	0	n/a	n/a	0.7	43	1.4	0.3	0	0	0.00	32	< 3	11	14	43	43	27	< 2.0	9
Pot 1	5	0-15	30	n/a	n/a	2.8	43	1.4	0.3	1257	145	0.04	707	8	316	324	1301	1023	587	6.6	263
Pot 2	5	0-15	30	n/a	n/a	2.3	43	1.4	0.3	1257	145	0.04	600	2	326	328	1301	926	498	1.8	271
Pot 3	5	0-15	30	n/a	n/a	2.2	43	1.4	0.3	1257	145	0.04	558	1	248	249	1301	806	463	1.1	206
Pot 1	5	0-15	100	n/a	n/a	5.6	43	1.4	0.3	4189	484	0.13	2484	8	355	363	4236	2839	1949	6.2	278
Pot 2	5	0-15	100	n/a	n/a	5.9	43	1.4	0.3	4189	484	0.13	2738	6	437	443	4236	3175	2148	4.5	343
Pot 3	5	0-15	100	n/a	n/a	6.0	43	1.4	0.3	4189	484	0.13	2138	6	336	342	4236	2474	1678	4.4	263
Pot 1	5	0-15	300	n/a	n/a	11.5	43	1.4	0.3	12567	1451	0.39	8912	26	974	999	12621	9887	6044	17.3	661
Pot 2	5	0-15	300	n/a	n/a	11.3	43	1.4	0.3	12567	1451	0.39	6529	25	870	894	12621	7398	4428	16.6	590
Pot 3	5	0-15	300	n/a	n/a	10.8	43	1.4	0.3	12567	1451	0.39	6713	34	875	909	12621	7588	4553	23.3	593

All samples were analyzed in the BIOE Laboratory.

LEACHING EXP. - RUN 2 (COLUMNS) - NITROGEN, pH, EC, LOI - LONG FORM OF DATA ANALYSIS

	Class	Levels	Values				
Data for 0-45 cm Layers:							
	APPL	4	_ 0 dt/ha	_ 30 dt/ha	_100 dt/ha	_300 dt/ha	
	LENGTH	3	_0-45 cm Col.		_0-60 cm Col.		_0-90 cm Col.

Number of observations for LOI in the 0-15 cm Layer = 21 (DF for Error = 9)
Number of observations for LOI in the 15-30 cm Layer = 19 (DF for Error = 7)
Number of observations for all other parameters = 26 (DF for Error = 14)

	Class	Levels	Values			
Data for 45-60 cm Layer:						
	APPL	4	_ 0 dt/ha	_ 30 dt/ha	_100 dt/ha	_300 dt/ha
	LENGTH	2	_0-60 cm Col.		_0-90 cm Col.	

Number of observations in data set = 18 (DF for Error = 10)

	Class	Levels	Values			
Data for 60-90 cm Layers:						
	APPL	4	_ 0 dt/ha	_ 30 dt/ha	_100 dt/ha	_300 dt/ha
	LENGTH	1	_0-90 cm Col.			

Number of observations in data set = 10 (DF for Error = 6)

Notes:
All samples were analyzed in the BIOE Lab.
The factorial model y=LENGTH|APPL and the Duncan multiple range test at the 0.05 level of probability was used to determine significantly different means.
'R-Square' refers to the R^2 of the factorial model in the SAS procedure GLM.
'Std. Dev. ' refers to the sample standard deviation.
'C.V.' refers to the coefficient of variation in percent.
'N' refers to the number of samples for average calculations.
Means preceded by different letters are significantly different.
In the analysis, if the concentration measured was below the detection limit, half the concentration of the detection limit was used for that element.

		R-Square:	C.V.:	Std. Dev.:	Mean:
0-15 cm Layer:					
1:2 pH		0.481	2.8	0.2	7.3
1:2 EC	**(dS/m)**	0.293	66	1.3	2.0
LOI	**(%)**	APPL sig.			
TKN	**(mg/kg)**	APPL sig.			
NH4-N	**(mg/kg)**	0.633	96	87.2	90.4
NO3-N	**(mg/kg)**	APPL sig.			

0-15 cm Loss on Ignition (%):

Duncan Grouping	Mean	N	APPL
A	11.1	8	_300 dt/ha
B	5.0	6	_100 dt/ha
C	2.5	4	_ 30 dt/ha
D	1.2	3	_ 0 dt/ha

0-15 cm TKN (mg/kg):

Duncan Grouping	Mean	N	APPL
A	4791	8	_300 dt/ha
B	2252	6	_100 dt/ha
C	725	6	_ 30 dt/ha
D	52	6	_ 0 dt/ha

0-15 cm NO3-N (mg/kg):

Duncan Grouping		Mean	N	APPL
A		928	8	_300 dt/ha
B	A	702	6	_100 dt/ha
B	C	235	6	_ 30 dt/ha
C		0.1	6	_ 0 dt/ha

LEACHING EXP. - RUN 2 (COLUMNS) - NITROGEN, pH, EC, LOI - LONG FORM OF DATA ANALYSIS

		R-Square:	C.V.:	Std. Dev.:	Mean:
15-30 cm Layer:					
1:2 pH		0.341	3.1	0.2	7.5
1:2 EC	**(dS/m)**	0.462	75	1.0	1.3
LOI	**(%)**	APPL sig.			
TKN	**(mg/kg)**	APPL sig.			
NH4-N	**(mg/kg)**	APPL sig.			
NO3-N	**(mg/kg)**	0.645	141	144	102

15-30 cm Loss on Ignition (%):

Duncan Grouping	Mean	N	APPL
A	8.7	8	_300 dt/ha
B	1.8	6	_100 dt/ha
B	1.1	3	_ 30 dt/ha
B	1.0	2	_ 0 dt/ha

15-30 cm TKN (mg/kg):

Duncan Grouping	Mean	N	APPL
A	4401	8	_300 dt/ha
B	583	6	_100 dt/ha
B	151	6	_ 30 dt/ha
B	40	6	_ 0 dt/ha

15-30 cm NH4-N (mg/kg):

Duncan Grouping	Mean	N	APPL
A	723	8	_300 dt/ha
B	255	6	_100 dt/ha
C	46	6	_ 30 dt/ha
C	1	6	_ 0 dt/ha

		R-Square:	C.V.:	Std. Dev.:	Mean:
30-45 cm Layer:					
1:2 pH		APPL sig.			
1:2 EC	**(dS/m)**	0.192	60	0.3	0.6
LOI	**(%)**	not analyzed			
TKN	**(mg/kg)**	APPL sig.			
NH4-N	**(mg/kg)**	APPL sig.			
NO3-N	**(mg/kg)**	0.604	156	40.2	25.7

30-45 cm 1:2 pH:

Duncan Grouping		Mean	N	APPL
A		7.8	8	_300 dt/ha
B		7.5	6	_100 dt/ha
C	B	7.4	6	_ 30 dt/ha
C		7.3	6	_ 0 dt/ha

30-45 cm TKN (mg/kg):

Duncan Grouping	Mean	N	APPL
A	386	8	_300 dt/ha
B	69	6	_100 dt/ha
B	30	6	_ 30 dt/ha
B	26	6	_ 0 dt/ha

30-45 cm NH4-N (mg/kg):

Duncan Grouping		Mean	N	APPL
A		251	8	_300 dt/ha
B		39	6	_100 dt/ha
C	B	6	6	_ 30 dt/ha
C		1	6	_ 0 dt/ha

LEACHING EXP. - RUN 2 (COLUMNS) - NITROGEN, pH, EC, LOI - LONG FORM OF DATA ANALYSIS

		R-Square:	C.V.:	Std. Dev.:	Mean:
45-60 cm Layer:					
1:2 pH		0.574	1.3	0.1	7.5
1:2 EC	**(dS/m)**	0.047	61	0.3	0.5
LOI	**(%)**	not analyzed			
TKN	**(mg/kg)**	0.544	74	21.1	28.6
NH4-N	**(mg/kg)**	0.432	220	18.2	8.2
NO3-N	**(mg/kg)**	0.623	133	1.0	0.7

		R-Square:	C.V.:	Std. Dev.:	Mean:
60-75 cm Layer:					
1:2 pH		0.457	1.1	0.1	7.4
1:2 EC	**(dS/m)**	0.039	56	0.3	0.6
LOI	**(%)**	not analyzed			
TKN	**(mg/kg)**	0.249	56	11.2	20.0
NH4-N	**(mg/kg)**	0.179	91	2.4	2.6
NO3-N	**(mg/kg)**	0.312	143	0.5	0.4

		R-Square:	C.V.:	Std. Dev.:	Mean:
75-90 cm Layer:					
1:2 pH		0.300	1.5	0.1	7.4
1:2 EC	**(dS/m)**	0.069	63.3	0.5	0.7
LOI	**(%)**	not analyzed			
TKN	**(mg/kg)**	0.229	61.3	8.3	13.6
NH4-N	**(mg/kg)**	0.304	72.4	1.2	1.7
NO3-N	**(mg/kg)**	0.000	0.0	0.0	0.1

LEACHING EXP. - RUN 2 (POTS) - NITROGEN, pH, EC, LOI - LONG FORM OF DATA ANALYSIS

Class	Levels	Values			
APPL	4	_ 0 dt/ha	_ 30 dt/ha	_100 dt/ha	_300 dt/ha

Number of observations in data set = 10 (DF for Error = 6)

Pot Trial:

1:2 pH		not analyzed
1:2 EC	**(dS/m)**	not analyzed
LOI	**(%)**	APPL sig.
TKN	**(mg/kg)**	APPL sig.
NH4-N	**(mg/kg)**	APPL sig.
NO3-N	**(mg/kg)**	APPL sig.

Loss on Ignition (%):

Duncan Grouping	Mean	N	APPL
A	11.2	3	_300 dt/ha
B	5.8	3	_100 dt/ha
C	2.4	3	_ 30 dt/ha
D	0.7	1	_ 0 dt/ha

TKN (mg/kg):

Duncan Grouping	Mean	N	APPL
A	5008	3	_300 dt/ha
B	1925	3	_100 dt/ha
C	516	3	_ 30 dt/ha
C	27	1	_ 0 dt/ha

NH4-N (mg/kg):

Duncan Grouping	Mean	N	APPL
A	19.1	3	_300 dt/ha
B	5.0	3	_100 dt/ha
B	3.2	3	_ 30 dt/ha
B	1.0	1	_ 0 dt/ha

NO3-N (mg/kg):

Duncan Grouping	Mean	N	APPL
A	615	3	_300 dt/ha
B	295	3	_100 dt/ha
B	247	3	_ 30 dt/ha
C	9	1	_ 0 dt/ha

APPENDIX F

Leaching Run 1 - Total Metals in Soil

LEACHING EXPERIMENT - RUN 1 - TOTAL METALS - OVERVIEW

Class Level Information

Class	Levels	Values		
APPL	3	_ 0 dt/ha	_100 dt/ha	_300 dt/ha
LENGTH	2	_0-45 cm Col.		_0-90 cm Col.

Number of observations in data set = 12 (DF for Error = 6)

LEACHING RUN 1												
DEPTH		Arsenic (mg/kg)	Cadmium (mg/kg)	Chromium (mg/kg)	Cobalt (mg/kg)	Copper (mg/kg)	Lead (mg/kg)	Mercury (mg/kg)	Molybd. (mg/kg)	Nickel (mg/kg)	Selenium (mg/kg)	Zinc (mg/kg)
0 - 15 cm	Mean	< 8.0	0.7	41.6	16.0	1080	14.6	APPL sig.	0.7	18.9	0.6	APPL sig.
	Std. Dev.		0.3	3.8	1.2	71	3.1		0.2	2.2	0.3	
15 - 30 cm	Mean	< 8.0	0.4	50.6	18.0	1578	8.1	0.2	0.7	22.5	0.4	91.5
	Std. Dev.		0.2	2.2	1.6	169	4.7	0.1	0.2	2.1	0.1	9.0
30 - 45 cm	Mean	< 8.0	0.4	54.8	18.5	1528	4.1	< 0.1	0.6	24.5	0.3	88.8
	Std. Dev.		0.3	6.3	2.1	157	1.9		0.2	2.8	0.1	6.7
Normal Range *		1 - 50	0.01 - 7	5 - 1000	1 - 40	2 - 100	2 - 200	0.02 - 0.2	0.2 - 5	10 - 1000	0.1 - 2	10 - 300
Typical Concentration *		5	0.06	20	8	20	10	0.05	2	40	0.5	50
CCME **		20	3	250	40	100	375	0.8	5	100	2	500

TOTAL METALS	Depth	0 dt/ha	100 dt/ha	300 dt/ha
Mercury	0-15 cm	0.1 c	0.5 b	1.2 a
Zinc	0-15 cm	69 c	107 b	163 a

Notes:
The factorial model with parameters APPL (application rate) and LENGTH (Column length) was run on the data.
The Duncan multiple range test at the 0.05 level of probability was used to determine significantly different means.
In the analysis, if the concentration measured was below the detection limit, half the concentr. of the detection limit was used in average calculations.
'Std. Dev. ' refers to the sample standard deviation.
Means followed by different letters are significantly different.
All samples were analyzed in the GVRD Lab.

* Bohn et al., 1985
** Lowest of the remediation limits for agricultural or residential soils set by the Canadian Council of Ministers of the Environment (1991)

LEACHING EXPERIMENT - RUN 1 - LABORATORY DATA - TOTAL METALS

Col.	Depth	Tailings from Site	Column Length	Appl. Rate	Total Arsenic	Total Cadmium	Total Chromium	Total Cobalt	Total Copper	Total Lead	Total Mercury	Total Molybd.	Total Nickel	Total Selenium	Total Zinc
	(cm)		(cm)	(dt/ha)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)
C1	0-15	1	0-90	0	< 7	0.9	40	16.9	1265	4.9	< 0.1	< 0.1	16.9	0.3	70
C1	15-30	1	0-90	0	< 7	0.4	51	17.4	1748	7.6	< 0.1	< 0.1	22.7	0.3	84
C1	30-45	1	0-90	0	< 7	0.9	55	18.8	1521	4.8	< 0.1	< 0.1	24.2	0.3	92
C3	0-15	1	0-90	100	< 7	0.8	40	15.6	1156	18.4	0.6	< 1.4	18.4	0.6	115
C3	15-30	1	0-90	100	< 7	0.4	52	17.2	1671	10.6	0.1	< 1.3	22.5	0.3	82
C3	30-45	1	0-90	100	< 7	0.5	48	20.0	1504	< 4.7	< 0.1	< 1.3	21.3	0.3	84
C4 & C5	0-15	1	0-90	300	< 8	1.0	39	15.5	966	27.4	1.1	< 1.6	17.7	0.8	156
C4 & C5	15-30	1	0-90	300	< 8	0.5	44	16.7	1239	18.2	0.6	< 1.5	19.7	0.5	117
C4 & C5	30-45	1	0-90	300	< 7	< 0.4	54	17.6	1615	5.8	< 0.1	< 1.4	23.1	0.3	77
C6	0-15	1	0-45	0	< 6	< 0.5	39	16.2	1153	< 4.5	< 0.1	< 1.4	17.4	0.2	66
C6	15-30	1	0-45	0	< 7	0.4	52	17.9	1747	4.7	0.3	< 1.4	22.0	0.3	83
C6	30-45	1	0-45	0	< 7	0.4	48	17.3	1546	6.1	< 0.1	< 1.3	21.3	0.3	85
C8	0-15	1	0-45	100	< 7	1.0	38	16.4	1103	4.5	0.4	< 1.4	17.8	0.5	112
C8	15-30	1	0-45	100	< 7	< 0.4	49	17.4	1469	< 4.1	< 0.1	< 1.3	20.0	0.4	81
C8	30-45	1	0-45	100	< 7	0.4	49	18.5	1800	< 4.5	< 0.1	< 1.5	23.8	0.3	97
C9	0-15	1	0-45	300	< 8	1.1	39	13.9	993	26.3	1.2	< 1.5	18.6	0.9	155
C9	15-30	1	0-45	300	< 7	< 0.4	49	15.3	1490	6.3	0.1	< 1.4	19.5	0.4	88
C9	30-45	1	0-45	300	< 7	< 0.4	51	16.5	1649	< 4.1	< 0.1	< 1.4	22.0	0.4	80

All samples were analyzed in the GVRD Laboratory using analytical methods described in Appendix O.
Refer to Appendix N for detection and quantitation limits for all metals listed in this table.

LEACHING EXPERIMENT - RUN 1 - LABORATORY DATA - TOTAL METALS

Col.	Depth	Tailings from Site	Colunm Length	Appl. Rate	Total Arsenic	Total Cadmium	Total Chromium	Total Cobalt	Total Copper	Total Lead	Total Mercury	Total Molybd.	Total Nickel	Total Selenium	Total Zinc
	(cm)		(cm)	(dt/ha)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)
C-A	0-15	2	0-90	0	< 6	< 0.4	45	16.8	1208	< 4.1	< 0.1	< 1.3	20.7	0.3	71
C-A	15-30	2	0-90	0	< 7	< 0.5	52	18.8	1397	< 4.8	< 0.1	< 1.5	24.2	0.4	79
C-A	30-45	2	0-90	0	< 7	< 0.4	68	16.3	1240	< 4.3	< 0.1	< 1.4	27.1	0.3	91
C-C	0-15	2	0-90	100	< 7	0.4	45	16.1	1141	13.6	0.6	< 1.5	20.5	0.6	104
C-C	15-30	2	0-90	100	< 7	< 0.4	54	17.9	1750	< 4.1	< 0.1	< 1.4	24.8	0.4	83
C-C	30-45	2	0-90	100	< 7	< 0.4	61	16.3	1219	< 3.9	< 0.1	< 1.4	24.4	0.3	85
C-D & C-E	0-15	2	0-90	300	< 8	1.0	46	16.0	1005	32.1	1.5	< 1.7	22.0	1.7	182
C-D & C-E	15-30	2	0-90	300	< 7	0.4	51	19.4	1639	13.0	0.3	< 1.5	22.4	0.4	106
C-D & C-E	30-45	2	0-90	300	< 7	< 0.4	57	19.6	1397	5.2	< 0.1	< 1.4	25.1	0.3	89
C-F	0-15	2	0-45	0	< 6	< 0.5	44	18.7	1039	4.6	< 0.1	< 1.4	19.9	0.2	70
C-F	15-30	2	0-45	0	< 7	0.4	53	19.9	1684	5.8	< 0.1	< 1.3	25.2	0.3	89
C-F	30-45	2	0-45	0	< 7	0.4	56	19.1	1388	4.8	< 0.1	< 1.4	27.2	0.3	93
C-H	0-15	2	0-45	100	< 7	0.7	38	13.6	901	11.8	0.4	< 1.4	15.4	0.4	97
C-H	15-30	2	0-45	100	< 7	0.4	51	20.5	1682	7.8	< 0.1	< 1.4	24.6	0.3	92
C-H	30-45	2	0-45	100	< 7	0.8	54	20.3	1627	4.2	< 0.1	< 1.4	27.1	0.1	94
C-I	0-15	2	0-45	300	< 8	0.8	46	15.8	1029	27.7	1.1	< 1.6	21.2	0.7	160
C-I	15-30	2	0-45	300	< 7	0.9	49	17.7	1424	16.3	0.3	<1.5	22.2	0.4	114
C-I	30-45	2	0-45	300	< 7	0.4	57	21.3	1832	7.5	< 0.1	< 1.4	27.0	0.3	98

All samples were analyzed in the GVRD Laboratory using analytical methods described in Appendix O.
Refer to Appendix N for detection and quantitation limits for all metals listed in this table.

LEACHING EXP. - RUN 1 - TOTAL METALS - LONG FORM OF DATA ANALYSIS

Class Level Information

Class	Levels	Values		
APPL	3	_ 0 dt/ha	_100 dt/ha	_300 dt/ha
LENGTH	2	_0-45 cm Col.		_0-90 cm Col.

Number of observations in data set = 12 (DF for Error = 6)

Notes:
The factorial model with parameters APPL (application rate) and LENGTH (col. length) was run on the data.
'R-Square' refers to the R^2 of the model y = APPL | LENGTH in the statistical SAS procedure GLM.
The Duncan multiple range test at the 0.05 level of probability was used to determine significantly different means.
'Std. Dev. ' refers to the sample standard deviation.
'C.V.' refers to the coefficient of variation in percent.
'N' refers to the number of samples for average calculations.
Means preceded by different letters are significantly different.
In the analysis, if the concentration measured was below the detection limit, half the concentration of the detection limit was used for that element.

		R-Square:	**C.V.:**	**Std. Dev.:**	**Mean:**
0-15 cm Layer:					
Arsenic	**(mg/kg)**	all values			< 8.0
Cadmium	**(mg/kg)**	0.639	37.1	0.3	0.7
Chromium	**(mg/kg)**	0.273	9.1	3.8	41.6
Cobalt	**(mg/kg)**	0.534	7.7	1.2	16
Copper	**(mg/kg)**	0.766	6.6	71	1080
Lead	**(mg/kg)**	0.96	21.1	3.1	14.6
Mercury	**(mg/kg)**	APPL sig.			
Molybd.	**(mg/kg)**	0.607	25.8	0.2	0.7
Nickel	**(mg/kg)**	0.35	11.5	2.2	18.9
Selenium	**(mg/kg)**	0.774	44.6	0.3	0.6
Zinc	**(mg/kg)**	APPL. sig.			

0-15 cm Mercury (mg/kg):

Duncan Grouping	Mean	N	APPL
A	1.2	4	_300 dt/ha
B	0.5	4	_100 dt/ha
C	0.1	4	_ 0 dt/ha

0-15 cm Zinc (mg/kg):

Duncan Grouping	Mean	N	APPL
A	163	4	_300 dt/ha
B	107	4	_100 dt/ha
C	69	4	_ 0 dt/ha

LEACHING EXP. - RUN 1 - TOTAL METALS - LONG FORM OF DATA ANALYSIS

15-30 cm Layer:		R-Square:	C.V.:	Std. Dev.:	Mean:
Arsenic	**(mg/kg)**	all values			< 8.0
Cadmium	**(mg/kg)**	0.242	56.6	0.2	0.4
Chromium	**(mg/kg)**	0.606	4.4	2.2	50.6
Cobalt	**(mg/kg)**	0.365	8.6	1.6	18
Copper	**(mg/kg)**	0.451	10.7	169	1578
Lead	**(mg/kg)**	0.599	57.9	4.7	8.1
Mercury	**(mg/kg)**	0.681	82.8	0.1	0.2
Molybd.	**(mg/kg)**	0.390	31.4	0.2	0.7
Nickel	**(mg/kg)**	0.383	9.4	2.1	22.5
Selenium	**(mg/kg)**	0.571	15.7	0.1	0.4
Zinc	**(mg/kg)**	0.748	9.9	9	92

30-45 cm Layer:		R-Square:	C.V.:	Std. Dev.:	Mean:
Arsenic	**(mg/kg)**	all values			< 8.0
Cadmium	**(mg/kg)**	0.371	63.7	0.3	0.4
Chromium	**(mg/kg)**	0.355	11.4	6.3	54.8
Cobalt	**(mg/kg)**	0.135	11.4	2.1	18.5
Copper	**(mg/kg)**	0.643	10.3	157	1528
Lead	**(mg/kg)**	0.463	46.1	1.9	4.1
Mercury	**(mg/kg)**	all values			< 0.1
Molybd.	**(mg/kg)**	0.448	29.5	0.2	0.6
Nickel	**(mg/kg)**	0.182	11.4	2.8	24.5
Selenium	**(mg/kg)**	0.492	22.1	0.1	0.3
Zinc	**(mg/kg)**	0.435	7.6	7	89

APPENDIX G

Leaching Run 2 - Total Metals in Soil

LEACHING EXPERIMENT - RUN 2 (COLUMNS) - TOTAL METALS - OVERVIEW

Class Level Information

Class	Levels	Values		
APPL	3	_ 0 dt/ha	_100 dt/ha	_300 dt/ha
LENGTH	2	_0-45 cm Col.		_0-90 cm Col.

Number of observations in data set = 12 (DF for Error = 6)

LEACHING RUN 2												
DEPTH		**Arsenic (mg/kg)**	**Cadmium (mg/kg)**	**Chromium (mg/kg)**	**Cobalt (mg/kg)**	**Copper (mg/kg)**	**Lead (mg/kg)**	**Mercury (mg/kg)**	**Molybd. (mg/kg)**	**Nickel (mg/kg)**	**Selenium (mg/kg)**	**Zinc (mg/kg)**
0-15 cm	**Mean**	< 8.0	0.8	50.7	18.9	1613	APPL sig.	APPL sig.	1.4	21.6	APPL sig.	APPL sig.
	Std. Dev.		0.2	2.9	1.5	83			0.6	2.2		
15-30 cm	**Mean**	< 8.0	0.6	56.8	APPL sig.	1856	APPL sig.	APPL sig.	1.1	25.3	APPL sig.	APPL sig.
	Std. Dev.		0.2	6.2		210			0.5	2.1		
30-45 cm	**Mean**	< 8.0	0.5	62.5	24.6	2168	6.8	< 0.1	0.9	28.5	0.5	111.3
	Std. Dev.		0.2	5.8	2.1	476	5.5		0.5	3.1	0.1	16.2
Normal Range *		1 - 50	0.01 - 7	5 - 1000	1 - 40	2 - 100	2 - 200	0.02 - 0.2	0.2 - 5	10 - 1000	0.1 - 2	10 - 300
Typical Concentration *		5	0.06	20	8	20	10	0.05	2	40	0.5	50
CCME **		20	3	250	40	100	375	0.8	5	100	2	500

Notes:
The factorial model with parameters APPL (application rate) and LENGTH (Column length) was run on the data.
The Duncan multiple range test at the 0.05 level of probability was used to determine significantly different means.
In the analysis, if the concentration measured was below the detection limit, half the concent. of the detection limit was used in average calculations.
'Std. Dev. ' refers to the sample standard deviation.
All samples were analyzed in the GVRD Lab.

* Bohn et al., 1985
** Lowest of the remediation limits for agricultural or residential soils set by the Canadian Council of Ministers of the Environment (1991)

LEACHING EXP. - RUN 2 (COLUMNS) - METALS - SIG. PARAMETERS

Class Level Information

Class	Levels	Values		
APPL	3	_ 0 dt/ha	_100 dt/ha	_300 dt/ha
LENGTH	2	_0-45 cm Col.		_0-90 cm Col.

Number of observations in data set = 12 (DF for Error = 6)

LEAD			
Depth/Applic.	0 dt/ha	100 dt/ha	300 dt/ha
0-15 cm	6.8 c	11.8 b	27.8 a
15-30 cm	5.6 b	6.8 b	21.0 a
30-45 cm	Average value		6.8

MERCURY			
Depth/Applic.	0 dt/ha	100 dt/ha	300 dt/ha
0-15 cm	0.1 c	0.3 b	0.9 a
15-30 cm	0.1 b	0.1 b	0.5 a
30-45 cm	Average value		< 0.1

SELENIUM			
Depth/Applic.	0 dt/ha	100 dt/ha	300 dt/ha
0-15 cm	0.4 c	0.7 b	1.4 a
15-30 cm	0.5 b	0.6 b	1.2 a
30-45 cm	Average value		0.5

ZINC			
Depth/Applic.	0 dt/ha	100 dt/ha	300 dt/ha
0-15 cm	82 c	120 b	182 a
15-30 cm	106 b	112 b	153 a
30-45 cm	Average value		111

COBALT			
Depth/Applic.	0 dt/ha	100 dt/ha	300 dt/ha
0-15 cm	Average value:		18.9
15-30 cm	24.3 a	24.0 a	19.5 b
30-45 cm	Average value		24.6

Notes:

The factorial model with parameters APPL (application rate) and LENGTH (col. length) was run on the data.

The Duncan multiple range test at the 0.05 level of probability was used to determine significantly different means.

Means followed by different letters are significantly different.

All samples were analyzed in the GVRD Lab.

MTRUN2D.XLS

LEACHING EXPERIMENT - RUN 2 (COLUMNS) - LABORATORY DATA - TOTAL METALS

Col.	Depth	Tailings from Site	Colunm Length	Appl. Rate	Total Arsenic	Total Cadmium	Total Chromium	Total Cobalt	Total Copper	Total Lead	Total Mercury	Total Molybd.	Total Nickel	Total Selenium	Total Zinc
	(cm)		(cm)	(dt/ha)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)
C1	0-15	3	0-90	0	< 5	1.0	51	19.0	1780	5	< 0.1	< 1.5	21.0	0.4	82
C1	15-30	3	0-90	0	< 5	0.5	66	24.0	1930	< 3	< 0.1	< 1.5	29.0	0.5	111
C1	30-45	3	0-90	0	< 5	0.5	63	24.0	2050	< 4	< 0.1	< 1.6	29.0	0.5	108
C3	0-15	3	0-90	100	< 5	0.5	48	18.0	1570	12	0.2	< 1.5	20.0	0.8	111
C3	15-30	3	0-90	100	< 5	0.5	65	24.0	1870	6	< 0.1	< 1.5	28.0	0.5	123
C3	30-45	3	0-90	100	< 5	< 0.5	46	19.0	1420	< 3	< 0.1	< 1.5	20.0	0.5	74
C4 & C5	0-15	3	0-90	300	< 5	1.0	48	17.0	1410	28	1.0	2.5	20.0	1.5	184
C4	15-30	3	0-90	300	< 5	1.0	52	19.0	1580	13	0.3	< 1.5	22.0	0.9	133
C5	15-30	3	0-90	300	< 5	1.0	50	18.0	1470	15	0.5	< 1.5	21.0	1.2	142
C4 & C5	30-45	3	0-90	300	< 5	1.0	65	26.0	1920	7	< 0.1	< 1.6	31.0	0.6	117
C6	0-15	3	0-45	0	< 4	0.4	46	18.0	1600	6	< 0.1	< 1.3	19.0	0.4	74
C6	15-30	3	0-45	0	< 5	0.5	62	24.0	1790	6	< 0.1	< 1.4	28.0	0.5	113
C6	30-45	3	0-45	0	< 5	0.5	62	23.0	1960	7	< 0.1	< 1.4	28.0	0.5	144
C8	0-15	3	0-45	100	< 5	1.0	50	18.0	1550	10	0.3	1.9	20.0	0.7	115
C8	15-30	3	0-45	100	< 5	0.5	66	24.0	1650	3	< 0.1	< 1.5	29.0	0.5	112
C8	30-45	3	0-45	100	< 5	< 0.5	69	26.0	1910	< 3	< 0.1	< 1.4	30.0	0.4	110
C9	0-15	3	0-45	300	< 5	0.9	50	18.0	1510	23	0.8	< 1.4	21.0	1.2	174
C9	15-30	3	0-45	300	< 5	0.5	52	18.0	1540	23	0.5	1.5	21.0	1.3	168
C9	30-45	3	0-45	300	< 5	0.5	67	25.0	1890	< 3	< 0.1	< 1.5	29.0	0.4	111

All samples were analyzed in the GVRD Laboratory using analytical methods described in Appendix O.
Refer to Appendix N for detection and quantitation limits for all metals listed in this table.

LEACHING EXPERIMENT - RUN 2 (COLUMNS) - LABORATORY DATA - TOTAL METALS

Col.	Depth	Tailings from Site	Colunm Length	Appl. Rate	Total Arsenic	Total Cadmium	Total Chromium	Total Cobalt	Total Copper	Total Lead	Total Mercury	Total Molybd.	Total Nickel	Total Selenium	Total Zinc
	(cm)		(cm)	(dt/ha)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)	(mg/kg)
C-A	0-15	4	0-90	0	< 5	< 0.5	52	20.0	1740	5	< 0.1	< 1.3	22.0	0.5	84
C-A	15-30	4	0-90	0	< 5	< 0.1	57	25.0	2230	7	< 0.1	< 1.6	26.0	0.4	103
C-A	30-45	4	0-90	0	< 5	0.5	63	24.0	2320	5	< 0.1	< 1.5	28.0	0.4	105
C-C	0-15	4	0-90	100	< 5	0.5	51	20.0	1640	12	0.4	2.2	22.0	0.7	128
C-C	15-30	4	0-90	100	< 5	< 0.5	51	24.0	1960	7	0.1	< 1.6	23.0	0.6	99
C-C	30-45	4	0-90	100	< 5	0.5	65	26.0	2530	12	< 0.1	< 1.6	30.0	0.5	116
C-D & D-E	0-15	4	0-90	300	< 5	1.0	52	19.0	1550	30	0.8	2.5	24.0	1.3	183
C-D	15-30	4	0-90	300	< 5	1.5	54	21.0	1750	27	0.6	2.4	23.0	1.1	170
C-E	15-30	4	0-90	300	< 4	0.9	49	20.0	1670	23	0.7	1.3	23.0	1.2	156
C-D & C-E	30-45	4	0-90	300	< 5	0.5	61	26.0	2410	12	< 0.1	< 1.5	28.0	0.6	112
C-F	0-15	4	0-45	0	< 5	0.5	53	22.0	1810	11	< 0.1	< 1.4	24.0	0.4	89
C-F	15-30	4	0-45	0	< 5	0.9	54	24.0	2130	8	< 0.1	< 1.4	26.0	0.6	98
C-F	30-45	4	0-45	0	< 4	0.4	61	24.0	2400	10	< 0.1	1.7	28.0	0.5	108
C-H	0-15	4	0-45	100	< 4	0.9	53	19.0	1660	13	0.3	1.3	23.0	0.6	125
C-H	15-30	4	0-45	100	< 5	0.5	55	24.0	2050	11	0.2	2.5	26.0	0.6	115
C-H	30-45	4	0-45	100	< 5	0.5	65	26.0	2660	11	< 0.1	2.0	31.0	0.6	115
C-I	0-15	4	0-45	300	< 5	1.0	54	19.0	1530	30	0.9	1.9	23.0	1.5	185
C-I	15-30	4	0-45	300	< 5	1.0	51	21.0	1890	22	0.6	1.9	23.0	1.2	142
C-I	30-45	4	0-45	300	< 5	0.5	63	26.0	2540	12	< 0.1	< 1.5	30.0	0.6	116

All samples were analyzed in the GVRD Laboratory using analytical methods described in Appendix O.
Refer to Appendix N for detection and quantitation limits for all metals listed in this table.

LEACHING EXP. - RUN 2 (COLUMNS) - TOTAL METALS - LONG FORM OF DATA ANALYSIS

Class Level Information

Class	Levels	Values		
APPL	3	_ 0 dt/ha	_100 dt/ha	_300 dt/ha
LENGTH	2	_0-45 cm Col.		_0-90 cm Col.

Number of observations in data set = 12 (DF for Error = 6)

Notes:
The factorial model with parameters APPL (application rate) and LENGTH (col. length) was run on the data.
'R-Square' refers to the R^2 of the model y = APPL | LENGTH in the statistical SAS procedure GLM.
The Duncan multiple range test at the 0.05 level of probability was used to determine significantly different means.
'Std. Dev. ' refers to the sample standard deviation.
'C.V.' refers to the coefficient of variation in percent.
'N' refers to the number of samples for average calculations.
Means preceded by different letters are significantly different.
In the analysis, if the concentration measured was below the detection limit, half the concentration of the detection limit was used for that element.

		R-Square:	C.V.:	Std. Dev.:	Mean:
0-15 cm Layer:					
Arsenic	**(mg/kg)**	all values:			< 8.0
Cadmium	**(mg/kg)**	0.701	27.8	0.2	0.8
Chromium	**(mg/kg)**	0.202	5.7	2.9	50.7
Cobalt	**(mg/kg)**	0.286	7.9	1.5	18.9
Copper	**(mg/kg)**	0.732	5.1	83	1613
Lead	**(mg/kg)**	APPL sig.			
Mercury	**(mg/kg)**	APPL sig.			
Molybd.	**(mg/kg)**	0.699	41.5	0.6	1.4
Nickel	**(mg/kg)**	0.046	10.3	2.2	21.6
Selenium	**(mg/kg)**	APPL sig.			
Zinc	**(mg/kg)**	APPL sig.			

0-15 cm Lead (mg/kg):

Duncan Grouping	Mean	N	APPL
A	27.8	4	_300 dt/ha
B	11.8	4	_100 dt/ha
C	6.8	4	_ 0 dt/ha

0-15 cm Mercury (mg/kg):

Duncan Grouping	Mean	N	APPL
A	0.9	4	_300 dt/ha
B	0.3	4	_100 dt/ha
C	0.1	4	_ 0 dt/ha

0-15 cm Selenium (mg/kg):

Duncan Grouping	Mean	N	APPL
A	1.4	4	_300 dt/ha
B	0.7	4	_100 dt/ha
C	0.4	4	_ 0 dt/ha

0-15 cm Zinc (mg/kg):

Duncan Grouping	Mean	N	APPL
A	182	4	_300 dt/ha
B	120	4	_100 dt/ha
C	82	4	_ 0 dt/ha

LEACHING EXP. - RUN 2 (COLUMNS) - TOTAL METALS - LONG FORM OF DATA ANALYSIS

		R-Square:	C.V.:	Std. Dev.:	Mean:
15-30 cm Layer:					
Arsenic	**(mg/kg)**	all values			< 8.0
Cadmium	**(mg/kg)**	0.720	37.2	0.2	0.6
Chromium	**(mg/kg)**	0.457	10.9	6.2	56.8
Cobalt	**(mg/kg)**	APPL sig.			
Copper	**(mg/kg)**	0.516	11.3	210	1856
Lead	**(mg/kg)**	APPL sig.			
Mercury	**(mg/kg)**	APPL sig.			
Molybd.	**(mg/kg)**	0.574	48.9	0.5	1.1
Nickel	**(mg/kg)**	0.711	8.3	2.1	25.3
Selenium	**(mg/kg)**	APPL sig.			
Zinc	**(mg/kg)**	APPL sig.			

15-30 cm	Cobalt (mg/kg):			
	Duncan Grouping	Mean	N	APPL
	A	24.3	4	_ 0 dt/ha
	A	24.0	4	_100 dt/ha
	B	19.5	4	_300 dt/ha

15-30 cm	Lead (mg/kg):			
	Duncan Grouping	Mean	N	APPL
	A	21.0	4	_300 dt/ha
	B	6.8	4	_100 dt/ha
	B	5.6	4	_ 0 dt/ha

15-30 cm	Mercury (mg/kg):			
	Duncan Grouping	Mean	N	APPL
	A	0.5	4	_300 dt/ha
	B	0.1	4	_100 dt/ha
	B	0.1	4	_ 0 dt/ha

15-30 cm	Selenium (mg/kg):			
	Duncan Grouping	Mean	N	APPL
	A	1.2	4	_300 dt/ha
	B	0.6	4	_100 dt/ha
	B	0.5	4	_ 0 dt/ha

15-30 cm	Zinc (mg/kg):			
	Duncan Grouping	Mean	N	APPL
	A	153	4	_300 dt/ha
	B	112	4	_100 dt/ha
	B	106	4	_ 0 dt/ha

		R-Square:	C.V.:	Std. Dev.:	Mean:
30-45 cm Layer:					
Arsenic	**(mg/kg)**	all values			< 8.0
Cadmium	**(mg/kg)**	0.500	33.7	0.2	0.5
Chromium	**(mg/kg)**	0.429	9.4	5.8	62.5
Cobalt	**(mg/kg)**	0.456	8.4	2.1	24.6
Copper	**(mg/kg)**	0.073	22.0	476	2168
Lead	**(mg/kg)**	0.205	79.8	5.5	6.8
Mercury	**(mg/kg)**	all values			< 0.1
Molybd.	**(mg/kg)**	0.350	50.8	0.5	0.9
Nickel	**(mg/kg)**	0.398	10.7	3.1	28.5
Selenium	**(mg/kg)**	0.349	17.0	0.1	0.5
Zinc	**(mg/kg)**	0.399	14.5	16	111

APPENDIX H

Leaching Run 1 - Nitrogen, Total Phosphorus, pH, and EC in Leachate

LEACHING EXPERIMENT - RUN 1 - NO3-N IN LEACHATE - OVERVIEW

Class Level Information

Class	Levels	Values			
APPL	4	_ 0 dt/ha	_ 30 dt/ha	_100 dt/ha	_300 dt/ha
LENGTH	3	_0-45 cm Col.		_0-60 cm Col.	_0-90 cm Col.

Number of observations in data set = 26 (DF for Error = 14)

LEACHING RUN 1		R-Square	C.V.	Std. Dev.:	Mean:
Total NO3-N/Column	**(mg/col.)**	0.419	267	0.13	0.05
Average NO3-N/Column	**(mg/L)**	0.419	201	0.04	0.02
Max. NO3-N/Col.	**(mg/L)**	0.379	238	0.49	0.21

Notes:
The factorial model with parameters APPL (application rate) and LENGTH (col. length) was applied to the data.
'R-Square' refers to the R^2 of the model y = APPL | LENGTH in the statistical SAS procedure GLM.
The Duncan multiple range test at the 0.05 level of probability was used to determine significantly different means.
'Std. Dev. ' refers to the sample standard deviation.
'C.V.' refers to the coefficient of variation in percent.
In the analysis, if the concentration measured was below the detection limit, half the concentration of the detection limit was used for that parameter.

LEACHING EXPERIMENT - RUN 1 - NO3-N IN LEACHATE

Col.	Tailings from Site	Col. Length	Applic. Rate	Total Leachate Water collected	Analyzed Leachate	Percent. of Leachate analyzed	Estimated mg NO3-N in Total Leachate	Estimated kg/ha NO3-N in Total Leachate	Maximum measured NO3-N Concentr.	Average weekly NO3-N concentration in leachate. Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 9	Week 10	Average NO3-N Concentr. per Column	Standard Deviation
										Mar. 15 -> 21	Mar. 22 -> 28	Mar. 29 -> Apr. 4	Apr. 5 -> 11	Apr. 12 -> 18	Apr. 19 -> 25	May 10 -> 16	May 17 -> 25		
		(cm)	(dt/ha)	(mL)	(mL)	(%)	(mg/Col.)	(kg/ha)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	
C1	1	0-90	0	1713	520	30%	0.01	0.00	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0
C2	1	0-90	30	2003	639	32%	0.01	0.00	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0
C3	1	0-90	100	2300	865	38%	0.01	0.00	0.015	0.005	0.005	0.005	0.005	0.005	0.005	0.008	0.005	0.005	0.0012
C4	1	0-90	300	2240	949	42%	0.01	0.00	0.010	0.005	0.005	0.005	0.005	0.005	0.005	0.007	0.005	0.005	0.0006
C5	1	0-90	300	1994	752	38%	0.01	0.00	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0
C6	1	0-45	0	1802	1790	99%	0.00	0.00	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0
C7	1	0-45	30	2100	2086	99%	0.00	0.00	0.013	0.005	0.005	0.008	0.005	0.005	0.005	0.005	0.005	0.005	0.0009
C8	1	0-45	100	2177	2102	97%	0.00	0.00	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0
C9	1	0-45	300	1941	1078	56%	0.00	0.00	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0
C10	1	0-60	0	2224	1512	68%	0.02	0.01	0.230	0.005	0.005	0.005	0.005	0.012	0.009	0.011	0.088	0.017	0.0285
C11	1	0-60	30	2187	1444	66%	0.00	0.00	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0
C12	1	0-60	100	2211	1372	62%	0.00	0.00	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0
C13	1	0-60	300	1913	1154	60%	0.00	0.00	0.019	0.005	0.005	0.005	0.005	0.005	0.005	0.010	0.008	0.006	0.0018
C-A	2	0-90	0	2125	793	37%	0.01	0.01	0.090	0.005	0.005	0.005	0.005	0.005	0.005	0.007	0.033	0.009	0.01
C-B	2	0-90	30	2267	775	34%	0.01	0.00	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0
C-C	2	0-90	100	2173	678	31%	0.01	0.00	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0
C-D	2	0-90	300	1982	637	32%	0.01	0.00	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0
C-E	2	0-90	300	2183	830	38%	0.14	0.09	0.750	0.253	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.036	0.088
C-F	2	0-45	0	2275	1997	88%	0.00	0.00	0.096	0.005	0.005	0.005	0.005	0.005	0.005	0.006	0.035	0.009	0.011
C-G	2	0-45	30	2211	2187	99%	0.32	0.21	0.93	0.068	0.550	0.053	0.005	0.005	0.005	0.005	0.082	0.097	0.186
C-H	2	0-45	100	2222	2158	97%	0.57	0.37	2.11	0.221	0.937	0.088	0.021	0.016	0.039	0.043	0.103	0.184	0.312
C-I	2	0-45	300	2415	1466	61%	0.04	0.02	0.57	0.005	0.005	0.005	0.005	0.005	0.005	0.035	0.193	0.032	0.066
C-J	2	0-60	0	2214	2177	98%	0.00	0.00	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0
C-K	2	0-60	30	2129	2078	98%	0.00	0.00	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0
C-L	2	0-60	100	2260	2134	94%	0.07	0.04	0.440	0.006	0.005	0.005	0.005	0.005	0.273	0.005	0.005	0.039	0.095
C-M	2	0-60	300	2420	1654	68%	0.00	0.00	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0

All samples were analyzed in the BIOE Laboratory.

LEACHING EXPERIMENT - RUN 1 - TKN - OVERVIEW

Class Level Information

Class	Levels	Values			
APPL	4	_ 0 dt/ha	_ 30 dt/ha	_100 dt/ha	_300 dt/ha
LENGTH	3	_0-45 cm Col.		_0-60 cm Col.	_0-90 cm Col.

Number of observations in data set = 26 (DF for Error = 14)

Notes:
The factorial model with parameters APPL (application rate) and LENGTH (col. length) was applied to the data.
'R-Square' refers to the R^2 of the model y = APPL | LENGTH in the statistical SAS procedure GLM.
The Duncan multiple range test at the 0.05 level of probability was used to determine significantly different means.
'Std. Dev. ' refers to the sample standard deviation.
'C.V.' refers to the coefficient of variation in percent.
'N' refers to the number of samples for average calculations.
Means preceded by different letters are significantly different.
If the concentration measured was below the detection limit, half the concentration of the detection limit was used in calculations.

LEACHING RUN 1		R-Square:	C.V.:	Std. Dev.:	Mean:	
Total TKN/Column	**(mg/col)**	0.625	121	1.2	1.0	
Max. TKN/Column	**(mg/L)**	0.302	177	5.5	3.1	
Week 1 - TKN	**(mg/L)**	0.227	354	1.9	0.5	
Week 2 - TKN	**(mg/L)**	0.446	162	0.3	0.2	
Week 3 - TKN	**(mg/L)**	0.524	199	1.0	0.5	
Week 4 - TKN	**(mg/L)**	APPL and LENGTH sig.				
Week 5 - TKN	**(mg/L)**	APPL, LENGTH, and APPL*LENGTH sig., but all values except for the Columns C-9 and C-I concentrations				< 2.7
Week 6 - TKN	**(mg/L)**	APPL, LENGTH, and APPL*LENGTH sig., but all values except for the Columns C-9 and C-I concentrations				< 1.2
Week 9 - TKN	**(mg/L)**	0.390	186	0.7	0.4	

where: Week 4 - TKN (mg/L):

Duncan Grouping		Mean	N	APPL
	a	1.2	8	_300 dt/ha
b	a	0.3	6	_ 30 dt/ha
b	a	0.3	6	_100 dt/ha
b		0.1	6	_ 0 dt/ha

Duncan Grouping	Mean	N	LENGTH
a	1.1	8	_0-45 cm Col.
b	0.3	10	_0-90 cm Col.
b	0.2	8	_0-60 cm Col.

Average TKN concentrations for Columns C-9 and C-I:

		Column: Appl. Rate: Col. Length:	C-9 & C-I 300 dt/ha 0-45 cm
Week 5 - TKN	**(mg/L)**		5.8
Week 6 - TKN	**(mg/L)**		6.7

LEACHING EXPERIMENT - RUN 1 - TKN IN LEACHATE

Col.	Tailings from Site	Col. Length	Applic. Rate	Total Leachate Water collected	Analyzed Leachate	Percent. of Leachate analyzed	Estimated mg TKN in Total Leachate	Estimated kg/ha TKN in Total Leachate	Maximum measured TKN Concentr.	Average weekly TKN concentration in leachate. Week 1 Mar. 15 -> 21	Week 2 Mar. 22 -> 28	Week 3 Mar. 29 -> Apr. 4	Week 4 Apr. 5 -> 11	Week 5 Apr. 12 -> 18	Week 6 Apr. 19 -> 25	Week 9 May 10 -> 16	Average TKN Conc.	Standard Dev.	C.V.
		(cm)	(dt/ha)	(mL)	(mL)	(%)	(mg/col.)	(kg/ha)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(%)
C1	1	0-90	0	1713	340	19.8%	0.6	0.4	1.4	< 0.20	< 0.20	< 0.20	0.32	0.37	0.50	1.37	0.4	0.4	100%
C2	1	0-90	30	2003	412	20.6%	1.0	0.7	2.8	< 0.20	< 0.20	0.27	0.35	0.21	0.50	2.77	0.6	1.0	167%
C3	1	0-90	100	2300	580	25.2%	0.4	0.2	0.8	< 0.20	< 0.20	< 0.20	0.46	0.35	< 0.20	< 0.20	0.2	0.2	100%
C4	1	0-90	300	2240	662	29.6%	0.5	0.3	1.6	< 0.20	< 0.20	< 0.20	0.55	0.93	< 0.20	< 0.20	0.3	0.3	100%
C5	1	0-90	300	1994	498	25.0%	0.7	0.5	2.2	< 0.20	< 0.20	< 0.20	1.15	0.77	0.36	0.54	0.4	0.4	100%
C6	1	0-45	0	1802	1764	97.9%	0.5	0.3	3.6	< 0.20	< 0.20	1.86	< 0.20	0.86	0.36	< 0.20	0.5	0.7	140%
C7	1	0-45	30	2100	2066	98.4%	0.2	0.1	1.4	< 0.20	< 0.20	< 0.20	0.76	0.22	0.36	< 0.20	0.3	0.2	67%
C8	1	0-45	100	2177	2060	94.6%	0.5	0.3	2.0	< 0.20	< 0.20	1.38	0.47	1.23	0.40	< 0.20	0.5	0.5	100%
C9	1	0-45	300	1941	889	45.8%	3.0	2.0	9.0	< 0.20	< 0.20	0.26	1.67	6.02	7.68	< 0.20	2.3	3.2	139%
C10	1	0-60	0	2224	1319	59.3%	0.1	0.1	0.1	< 0.20	< 0.20	< 0.20	< 0.20	< 0.20	< 0.20	< 0.20	0.1	0.0	0%
C11	1	0-60	30	2187	1270	58.1%	0.3	0.2	1.1	< 0.20	< 0.20	< 0.20	0.31	0.58	< 0.20	< 0.20	0.2	0.2	100%
C12	1	0-60	100	2211	1110	50.2%	0.3	0.2	1.1	< 0.20	< 0.20	< 0.20	< 0.20	< 0.20	0.60	< 0.20	0.2	0.2	100%
C13	1	0-60	300	1913	844	44.1%	0.3	0.2	1.8	< 0.20	< 0.20	< 0.20	0.31	0.93	< 0.20	< 0.20	0.2	0.3	150%
C-A	2	0-90	0	2125	508	23.9%	0.3	0.2	0.7	< 0.20	< 0.20	< 0.20	< 0.20	0.38	0.25	< 0.20	0.2	0.1	50%
C-B	2	0-90	30	2267	504	22.2%	0.4	0.3	0.8	0.33	< 0.20	0.40	< 0.20	0.44	< 0.20	< 0.20	0.2	0.2	100%
C-C	2	0-90	100	2173	444	20.4%	0.5	0.3	2.3	0.83	< 0.20	< 0.20	< 0.20	0.56	< 0.20	< 0.20	0.3	0.3	100%
C-D	2	0-90	300	1982	413	20.8%	0.6	0.4	1.5	0.43	< 0.20	< 0.20	< 0.20	0.40	0.79	< 0.20	0.3	0.3	100%
C-E	2	0-90	300	2183	596	27.3%	4.9	3.2	24.9	8.37	< 0.20	< 0.20	< 0.20	0.22	< 0.20	1.54	1.5	3.1	207%
C-F	2	0-45	0	2275	1849	81.3%	0.3	0.2	0.9	0.23	< 0.20	< 0.20	< 0.20	< 0.20	< 0.20	0.93	0.2	0.3	150%
C-G	2	0-45	30	2211	2142	96.9%	0.3	0.2	0.8	< 0.20	0.47	0.27	< 0.20	0.27	< 0.20	< 0.20	0.2	0.1	50%
C-H	2	0-45	100	2222	2074	93.3%	1.9	1.3	5.3	1.84	1.75	1.62	0.45	0.80	< 0.20	< 0.20	1.0	0.8	80%
C-I	2	0-45	300	2415	1125	46.6%	5.8	3.8	7.0	< 0.20	0.61	5.25	5.42	5.53	5.76	< 0.20	3.3	2.8	85%
C-J	2	0-60	0	2214	2162	97.7%	0.3	0.2	0.8	< 0.20	0.43	< 0.20	< 0.20	0.29	< 0.20	< 0.20	0.2	0.1	50%
C-K	2	0-60	30	2129	2048	96.2%	0.1	0.1	0.9	< 0.20	< 0.20	< 0.20	< 0.20	0.48	< 0.20	< 0.20	0.2	0.1	50%
C-L	2	0-60	100	2260	2030	89.8%	0.4	0.2	2.7	< 0.20	< 0.20	< 0.20	< 0.20	1.46	< 0.20	< 0.20	0.3	0.5	167%
C-M	2	0-60	300	2420	1396	57.7%	1.1	0.7	2.9	< 0.20	< 0.20	< 0.20	0.30	2.66	1.22	< 0.20	0.7	1.0	143%

All samples were analyzed in the BIOE Laboratory.
In statistical calculations, half the concentration of the detection limit was used for sample concentrations below the detection limit.
for sample concentrations below the detection limit.
'Standard Dev.' refers to the sample standard deviation.
'C.V.' refers to the coefficient of variation in percent.

LEACHING EXPERIMENT - RUN 1 - TOTAL P (PO4-P) IN LEACHATE

Col.	Tailings from Site	Col. Length	Applic. Rate	Total Leachate Water collected	Analyzed Leachate	Percent. of Leachate analyzed	Estimated mg TOTAL P in Total Leachate	Estimated kg/ha TOTAL P in Total Leachate	Maximum measured TOTAL P Concentr.	Average weekly TOTAL P (PO4-P) concentration in leachate. Week 1 Mar. 15 -> 21	Week 2 Mar. 22 -> 28	Week 3 Mar. 29 -> Apr. 4	Week 4 Apr. 5 -> 11	Week 5 Apr. 12 -> 18	Week 6 Apr. 19 -> 25	Average Total P Conc.	Standard Dev.	C.V.
		(cm)	(dt/ha)	(mL)	(mL)	(%)	(mg/col.)	(kg/ha)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(%)
C1	1	0-90	0	1713	262	15.3%	0.03	0.02	0.31	0.16	< 0.01	< 0.01	< 0.01	0.02	< 0.01	0.03	0.06	179%
C2	1	0-90	30	2003	295	14.7%	0.06	0.04	0.28	0.14	0.05	< 0.01	< 0.01	0.02	0.15	0.06	0.07	106%
C3	1	0-90	100	2300	522	22.7%	0.18	0.12	0.23	0.12	0.20	< 0.01	0.15	< 0.01	0.17	0.11	0.08	78%
C4	1	0-90	300	2240	576	25.7%	0.25	0.16	0.35	0.17	0.35	< 0.01	0.05	< 0.01	< 0.01	0.10	0.14	142%
C5	1	0-90	300	1994	417	20.9%	0.23	0.15	0.44	0.22	0.26	< 0.01	0.10	0.19	0.15	0.16	0.09	59%
C6	1	0-45	0	1802	1749	97.1%	0.12	0.08	0.29	< 0.01	0.29	< 0.01	0.29	< 0.01	0.14	0.12	0.14	114%
C7	1	0-45	30	2100	2046	97.4%	0.32	0.21	0.62	< 0.01	0.62	< 0.01	0.18	< 0.01	0.04	0.14	0.24	172%
C8	1	0-45	100	2177	1795	82.5%	0.40	0.26	0.62	< 0.01	0.62	< 0.01	0.23	0.38	0.05	0.22	0.25	114%
C9	1	0-45	300	1941	764	39.4%	0.86	0.56	1.70	0.15	1.70	< 0.01	0.16	< 0.01	0.42	0.41	0.65	160%
C10	1	0-60	0	2224	1150	51.7%	0.07	0.05	0.21	< 0.01	< 0.01	< 0.01	0.11	0.21	< 0.01	0.06	0.09	151%
C11	1	0-60	30	2187	1150	52.6%	0.20	0.13	0.38	< 0.01	0.38	< 0.01	< 0.01	< 0.01	0.04	0.07	0.15	207%
C12	1	0-60	100	2211	1010	45.7%	0.24	0.16	0.28	0.07	0.28	< 0.01	0.16	< 0.01	0.07	0.10	0.11	108%
C13	1	0-60	300	1913	751	39.3%	0.25	0.16	0.74	0.11	0.14	< 0.01	0.74	< 0.01	< 0.01	0.17	0.29	171%
C-A	2	0-90	0	2125	442	20.8%	0.03	0.02	0.06	< 0.01	< 0.01	< 0.01	< 0.01	0.06	0.05	0.02	0.03	113%
C-B	2	0-90	30	2267	391	17.2%	0.06	0.04	0.21	< 0.01	< 0.01	< 0.01	0.05	0.14	0.21	0.07	0.09	125%
C-C	2	0-90	100	2173	343	15.8%	0.14	0.09	0.54	0.13	0.28	< 0.01	< 0.01	0.04	0.09	0.09	0.10	114%
C-D	2	0-90	300	1982	323	16.3%	0.01	0.01	0.03	0.02	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.01	0.01	71%
C-E	2	0-90	300	2183	499	22.9%	0.37	0.24	0.78	0.17	0.78	< 0.01	0.06	< 0.01	< 0.01	0.17	0.31	177%
C-F	2	0-45	0	2275	1593	70.0%	0.47	0.31	0.49	0.18	0.49	< 0.01	0.09	< 0.01	0.12	0.15	0.18	122%
C-G	2	0-45	30	2211	2035	92.0%	0.46	0.30	0.90	< 0.01	0.90	< 0.01	0.13	0.09	< 0.01	0.19	0.35	185%
C-H	2	0-45	100	2222	1942	87.4%	0.73	0.48	0.86	0.18	0.86	< 0.01	-	< 0.01	0.36	0.28	0.36	126%
C-I	2	0-45	300	2415	973	40.3%	0.08	0.05	0.15	< 0.01	0.07	< 0.01	0.13	< 0.01	0.15	0.06	0.07	110%
C-J	2	0-60	0	2214	1867	84.3%	0.44	0.29	0.80	0.04	0.80	< 0.01	0.01	0.13	0.02	0.17	0.31	186%
C-K	2	0-60	30	2129	2016	94.7%	0.37	0.24	0.80	< 0.01	0.80	< 0.01	< 0.01	0.08	0.10	0.17	0.31	190%
C-L	2	0-60	100	2260	1845	81.6%	0.87	0.57	0.83	0.42	0.58	< 0.01	0.05	< 0.01	< 0.01	0.18	0.26	144%
C-M	2	0-60	300	2420	1224	50.6%	0.55	0.36	0.61	0.29	0.61	< 0.01	0.20	0.02	0.14	0.21	0.22	106%

All samples were analyzed in the BIOE Laboratory.
In statistical calculations, half the concentration of the detection limit was used for sample concentrations below the detection limit.
'-' Not enough leachate was collected to be able to conduct a TOTAL P analysis.
'Standard Dev.' refers to the sample standard deviation.
'C.V.' refers to the coefficient of variation in percent.

LEACHING EXPERIMENT - RUN 1 - pH OF LEACHATE

Col.	Tailings from Site	Col. Length	Applic. Rate	pH of leachate Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 9	Week 10	Average pH	Standard Dev.	C.V.
				Mar. 15 -> 21	Mar. 22 -> 28	Mar. 29 -> Apr. 4	Apr. 5 -> 11	Apr. 12 -> 18	Apr. 19 -> 25	May 10 -> 16	May 17 -> 25			
		(cm)	(dt/ha)											(%)
C1	1	0-90	0	8.2	8.1	8.2	8.2	8.4	8.2	8.0	8.2	8.2	0.1	1%
C2	1	0-90	30	8.3	8.2	8.2	8.2	8.3	8.3	8.1	8.3	8.2	0.1	1%
C3	1	0-90	100	8.2	8.2	8.3	8.3	8.3	8.3	8.0	-	8.2	0.1	1%
C4	1	0-90	300	8.1	8.2	8.3	8.3	8.4	8.3	8.1	8.2	8.2	0.1	1%
C5	1	0-90	300	8.2	8.2	8.2	8.3	8.4	8.3	8.1	8.1	8.2	0.1	1%
C6	1	0-45	0	8.1	8.1	8.2	8.2	8.3	8.3	-	-	8.2	0.1	1%
C7	1	0-45	30	8.1	8.0	8.3	8.2	8.3	8.3	-	-	8.2	0.1	1%
C8	1	0-45	100	8.1	8.0	8.2	8.3	8.3	8.3	-	-	8.2	0.1	1%
C9	1	0-45	300	8.3	8.2	8.3	8.2	8.4	8.3	-	-	8.3	0.1	1%
C10	1	0-60	0	8.1	8.0	8.3	8.2	8.2	8.1	7.4	7.6	8.0	0.3	4%
C11	1	0-60	30	8.1	8.1	8.3	8.3	8.3	8.3	-	-	8.2	0.1	1%
C12	1	0-60	100	8.1	8.0	8.3	8.2	8.4	8.3	-	-	8.2	0.1	1%
C13	1	0-60	300	8.1	8.0	8.2	8.3	8.3	8.2	8.1	8.3	8.2	0.1	1%
C-A	2	0-90	0	8.2	8.2	8.3	8.4	8.4	8.3	-	8.0	8.3	0.1	1%
C-B	2	0-90	30	8.2	8.2	8.3	8.4	8.4	8.3	8.2	8.2	8.3	0.1	1%
C-C	2	0-90	100	8.1	8.0	8.0	8.1	8.2	8.1	8.0	7.9	8.0	0.1	1%
C-D	2	0-90	300	7.9	8.0	8.0	8.1	8.1	8.0	7.9	7.9	8.0	0.1	1%
C-E	2	0-90	300	7.6	8.2	8.3	8.3	8.4	8.3	8.2	8.2	8.2	0.2	2%
C-F	2	0-45	0	8.1	8.1	8.2	8.1	8.3	8.2	7.4	6.6	7.9	0.6	8%
C-G	2	0-45	30	8.1	8.0	8.3	8.2	8.3	8.3	-	-	8.2	0.1	1%
C-H	2	0-45	100	8.1	8.1	8.3	8.3	8.4	8.1	-	8.3	8.2	0.1	1%
C-I	2	0-45	300	8.1	8.2	8.4	8.4	8.5	8.2	-	8.3	8.3	0.1	1%
C-J	2	0-60	0	8.1	8.1	8.3	8.2	8.3	8.3	-	6.3	8.0	0.7	9%
C-K	2	0-60	30	8.1	8.1	8.3	8.2	8.3	8.1	-	-	8.2	0.1	1%
C-L	2	0-60	100	8.1	8.2	8.3	8.3	8.4	8.0	-	-	8.2	0.2	2%
C-M	2	0-60	300	8.2	8.2	8.3	8.3	8.4	8.2	-	8.3	8.3	0.1	1%

All samples were analyzed in the BIOE Laboratory.
'Standard Dev.' refers to the sample standard deviation.
'C.V.' refers to the coefficient of variation in percent.
'-' Not enough leachate was collected to determine pH.

LEACHING EXPERIMENT - RUN 1 - ELECTRICAL CONDUCTIVITY OF LEACHATE

Col.	Tailings from Site	Col. Length	Applic. Rate	Electrical conductivity of leachate Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 9	Week 10	Average Conc.	Standard Dev.	C.V.
				Mar. 15 -> 21	Mar. 22 -> 28	Mar. 29 -> Apr. 4	Apr. 5 -> 11	Apr. 12 -> 18	Apr. 19 -> 25	May 10 -> 16	May 17 -> 25			
		(cm)	(dt/ha)	(dS/m)	(dS/m)	(dS/m)	(dS/m)	(dS/m)	(dS/m)	(dS/m)	(dS/m)	(dS/m)	(dS/m)	(%)
C1	1	0-90	0	2.40	1.60	1.60	1.50	1.50	1.50	1.40	1.30	1.6	0.3	21%
C2	1	0-90	30	1.40	1.58	1.58	1.45	1.60	1.58	1.58	1.40	1.5	0.1	6%
C3	1	0-90	100	1.60	1.58	1.50	1.30	1.30	1.22	-	-	1.4	0.2	11%
C4	1	0-90	300	1.45	1.40	1.24	1.10	1.20	1.10	-	-	1.3	0.2	12%
C5	1	0-90	300	1.60	1.60	1.50	1.40	1.41	1.41	1.40	-	1.5	0.1	6%
C6	1	0-45	0	0.38	0.35	0.37	0.38	0.39	0.42	-	-	0.4	0.0	5%
C7	1	0-45	30	0.38	0.36	0.50	0.61	0.75	0.87	-	-	0.6	0.2	34%
C8	1	0-45	100	0.38	0.44	0.79	0.95	1.20	1.40	-	-	0.9	0.4	48%
C9	1	0-45	300	0.41	0.38	0.40	0.76	1.20	1.80	-	-	0.8	0.6	70%
C10	1	0-60	0	0.56	0.48	0.46	0.40	0.34	0.34	0.20	0.16	0.4	0.1	38%
C11	1	0-60	30	0.56	0.48	0.52	0.66	0.76	0.81	-	-	0.6	0.1	21%
C12	1	0-60	100	0.56	0.49	0.48	0.50	0.56	0.88	-	-	0.6	0.2	26%
C13	1	0-60	300	0.54	0.48	0.46	0.44	0.42	0.50	-	-	0.5	0.0	9%
C-A	2	0-90	0	2.10	2.20	2.00	1.80	1.80	1.61	1.50	-	1.9	0.3	14%
C-B	2	0-90	30	2.00	2.00	1.95	1.80	1.70	1.65	1.50	1.40	1.8	0.2	13%
C-C	2	0-90	100	2.00	2.10	1.95	1.80	1.75	1.60	1.50	1.35	1.8	0.3	15%
C-D	2	0-90	300	2.00	2.20	2.00	1.90	1.80	1.65	1.42	1.40	1.8	0.3	16%
C-E	2	0-90	300	1.80	1.90	1.80	1.60	1.60	1.50	1.40	1.20	1.6	0.2	14%
C-F	2	0-45	0	0.69	0.59	0.56	0.53	0.51	0.50	0.11	-	0.5	0.2	36%
C-G	2	0-45	30	0.55	0.67	0.92	0.96	0.90	1.00	-	-	0.8	0.2	22%
C-H	2	0-45	100	0.60	1.00	1.42	1.60	1.60	1.60	-	1.40	1.3	0.4	29%
C-I	2	0-45	300	0.67	0.80	1.80	2.40	2.35	2.90	-	2.20	1.9	0.8	45%
C-J	2	0-60	0	0.80	0.70	0.63	0.60	0.58	0.60	-	-	0.7	0.1	12%
C-K	2	0-60	30	0.94	0.73	0.66	0.63	0.62	0.66	-	-	0.7	0.1	17%
C-L	2	0-60	100	0.98	0.82	0.82	0.90	0.90	0.66	-	-	0.9	0.1	13%
C-M	2	0-60	300	0.96	0.87	0.92	1.00	1.20	1.60	-	-	1.1	0.3	25%

All samples were analyzed in the BIOE Laboratory.
'Standard Dev.' refers to the sample standard deviation.
'C.V.' refers to the coefficient of variation in percent.
'-' Not enough leachate was collected to measure the electrical conductivity.

APPENDIX I

Leaching Run 2 - Nitrogen, Total Phosphorus, pH, and EC in Leachate

LEACHING EXPERIMENT - RUN 2 - NO3-N IN LEACHATE - OVERVIEW

Class	Levels	Values			
APPL	4	_ 0 dt/ha	_ 30 dt/ha	_100 dt/ha	_300 dt/ha
LENGTH	3	_0-45 cm Col.	_0-60 cm Col.	_0-90 cm Col.	

Number of observations in data set for Site 3 and Site 4 each = 13 (DF for Error = 1)

Notes:
In Leaching Run 2, the NO3-N leaching behaviour differed between the tailings from sites 3 and 4. Therefore, a separate analysis was conducted on the data collected for these sites.

The factorial model with parameters APPL (application rate) and LENGTH (col. length) was applied to the data.
'R-Square' refers to the R^2 of the model y = APPL | LENGTH in the statistical SAS procedure GLM.
The Duncan multiple range test at the 0.05 level of probability was used to determine significantly different means.
'Std. Dev. ' refers to the sample standard deviation.
'C.V.' refers to the coefficient of variation in percent.
In the analysis, if the concentration measured was below the detection limit, half the concentration of the detection limit was used for that parameter.

LEACHING RUN 2 - SITE 3

		R-Square	C.V.	Std. Dev.:	Mean:		
Total NO3-N/Col.	**(mg/col)**	APPL, LENGTH, and APPL*LENGTH sig., but all values				<	0.3
Max. NO3-N/Col.	**(mg/L)**	APPL, LENGTH, and APPL*LENGTH sig., but all values				<	2.4
Week 1 - NO3-N	**(mg/L)**	APPL, LENGTH, and APPL*LENGTH sig., but all values				<	0.3
Week 2 - NO3-N	**(mg/L)**	APPL, LENGTH, and APPL*LENGTH sig., but all values				<	0.1
Week 3 - NO3-N	**(mg/L)**	APPL, LENGTH, and APPL*LENGTH sig., but all values				<	0.1
Week 4 - NO3-N	**(mg/L)**	0.521	79	0.01	0.02		
Week 5 - NO3-N	**(mg/L)**	APPL, LENGTH, and APPL*LENGTH sig., but all values				<	0.1
Week 8 - NO3-N	**(mg/L)**	APPL, LENGTH, and APPL*LENGTH sig., but all values				<	0.6
Week 9 - NO3-N	**(mg/L)**	APPL, LENGTH, and APPL*LENGTH sig., but all values				<	0.4
Week 12 - NO3-N	**(mg/L)**	APPL, LENGTH, and APPL*LENGTH sig., but all values				<	1.7
Week 13 - NO3-N	**(mg/L)**	APPL, LENGTH, and APPL*LENGTH sig., but all values				<	1.6

LEACHING RUN 2 - SITE 4

Total NO3-N/Col.	**(mg/col.)**	APPL, LENGTH, and APPL*LENGTH sig., but all values except for Column C-G and C-H concentrations	<	0.6
Max. NO3-N/Col.	**(mg/L)**	APPL, LENGTH, and APPL*LENGTH sig., but all values except for Column C-G and C-H concentrations	<	1.9
Week 1 - NO3-N	**(mg/L)**	APPL, LENGTH, and APPL*LENGTH sig., but all values	<	0.2
Week 2 - NO3-N	**(mg/L)**	APPL, LENGTH, and APPL*LENGTH sig., but all values	<	1.2
Week 3 - NO3-N	**(mg/L)**	APPL, LENGTH, and APPL*LENGTH sig., but all values	<	0.5
Week 4 - NO3-N	**(mg/L)**	APPL, LENGTH, and APPL*LENGTH sig., but all values	<	0.7
Week 5 - NO3-N	**(mg/L)**	APPL, LENGTH, and APPL*LENGTH sig., but all values	<	0.4
Week 8 - NO3-N	**(mg/L)**	APPL, LENGTH, and APPL*LENGTH sig., but all values except for Column C-G and C-H concentrations	<	0.2
Week 9 - NO3-N	**(mg/L)**	APPL, LENGTH, and APPL*LENGTH sig., but all values except for Column C-G and C-H concentrations	<	0.3
Week 12 - NO3-N	**(mg/L)**	APPL, LENGTH, and APPL*LENGTH sig., but all values except for Column C-G and C-H concentrations	<	0.9
Week 13 - NO3-N	**(mg/L)**	APPL, LENGTH, and APPL*LENGTH sig., but all values except for Column C-G and C-H concentrations	<	0.6

LEACHING EXPERIMENT - RUN 2 - NO3-N IN LEACHATE - OVERVIEW

Average NO3-N concentrations for Columns G and H (0-45 cm Columns):

		Col. G (30 dt/ha)	Col. H (100 dt/ha)
Total NO3-N/Col.	(mg/col.)	188	121
Max. NO3-N/Col.	(mg/L)	1245	1076
Week 8 - NO3-N	(mg/L)	24	129
Week 9 - NO3-N	(mg/L)	32	49
Week 12 - NO3-N	(mg/L)	706	249
Week 13 - NO3-N	(mg/L)	819	693

Mass of NO3-N in Leachate collected from Columns G and H in Weeks with high NO3-N Concentrations:

		Col. G (30 dt/ha)	Col. H (100 dt/ha)
Max. NO3-N/Col.	(mg/col.)	125	70
Week 8 - NO3-N	(mg/col.)	1	9
Week 9 - NO3-N	(mg/col.)	3	4
Week 12 - NO3-N	(mg/col.)	53	16
Week 13 - NO3-N	(mg/col.)	89	62

LEACHING EXPERIMENT - RUN 2 - NO3-N IN LEACHATE

Col.	Tailings from Site	Col. Length	Applic. Rate	Total Leachate Water collected	Analyzed Leachate	Percent. of Leachate analyzed	Estimated mg NO3-N in Total Leachate	Estimated kg/ha NO3-N in Total Leachate	Maximum measured NO3-N Concentr.	Average weekly NO3-N concentration in leachate. Week 1 Aug. 16 -> 22	Week 2 Aug. 23 -> 29	Week 3 Aug. 30 -> Sep. 5	Week 4 Sep. 6 -> 12	Week 5 Sep. 13 -> 19	Week 8 Oct. 4 -> 10	Week 9 Oct. 11 -> 17	Week 12 Nov. 1 -> 7	Week 13 Nov. 8-> 14
		(cm)	(dt/ha)	(mL)	(mL)	(%)	(mg/Col.)	(kg/ha)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)
C1	3	0-90	0	1275	464	36%	0.03	0.02	0.13	0.005	0.007	0.042	0.011	0.058	0.045	0.050	0.050	0.050
C2	3	0-90	30	1435	561	39%	0.02	0.02	0.06	0.005	0.005	0.006	0.011	0.058	0.043	0.050	0.050	0.050
C3	3	0-90	100	1258	350	28%	0.04	0.02	0.14	0.005	0.005	0.007	0.011	0.058	0.045	0.050	0.050	0.050
C4	3	0-90	300	1166	362	31%	0.06	0.04	0.31	0.051	0.005	0.008	0.011	0.058	0.045	0.050	0.050	0.256
C5	3	0-90	300	1327	408	31%	0.13	0.08	0.77	0.083	0.029	0.056	0.067	0.058	0.045	0.050	0.050	0.539
C6	3	0-45	0	1131	519	46%	0.21	0.13	1.07	0.052	0.090	0.096	0.023	0.001	0.565	0.391	1.070	0.050
C7	3	0-45	30	1135	478	42%	0.20	0.13	1.95	0.061	0.012	0.006	0.011	0.058	0.001	0.114	1.010	1.565
C8	3	0-45	100	1041	343	33%	0.31	0.20	1.66	0.343	0.084	0.008	0.011	0.058	0.001	0.363	1.660	1.280
C9	3	0-45	300	954	336	35%	0.18	0.12	2.39	0.124	0.009	0.008	0.011	0.058	0.004	0.050	1.480	0.975
C10	3	0-60	0	1339	561	42%	0.15	0.10	0.75	0.062	0.027	0.025	0.015	0.058	0.169	0.290	0.646	0.499
C11	3	0-60	30	1279	352	28%	0.12	0.08	0.28	0.252	0.091	0.049	0.039	0.058	0.043	0.097	0.251	0.050
C12	3	0-60	100	1343	410	31%	0.16	0.10	0.58	0.319	0.082	0.036	0.011	0.058	0.043	0.068	0.233	0.202
C13	3	0-60	300	935	270	29%	0.11	0.07	0.42	0.235	0.047	0.041	0.014	0.058	0.045	0.094	0.189	0.423
C-A	4	0-90	0	1481	707	48%	0.11	0.07	1.47	0.011	0.005	0.006	0.011	0.058	0.119	0.067	0.925	0.625
C-B	4	0-90	30	1243	354	29%	0.40	0.26	1.92	0.166	0.157	0.173	0.704	0.408	0.045	0.140	0.444	0.293
C-C	4	0-90	100	1464	512	35%	0.08	0.05	0.45	0.007	0.005	0.181	0.014	0.086	0.043	0.074	0.250	0.050
C-D	4	0-90	300	1435	480	34%	0.12	0.08	0.42	0.097	0.028	0.048	0.035	0.140	0.045	0.072	0.264	0.130
C-E	4	0-90	300	801	237	30%	0.19	0.12	0.93	0.205	0.130	0.143	0.354	0.298	0.043	0.071	0.926	0.340
C-F	4	0-45	0	1527	842	55%	0.65	0.42	1.47	0.024	1.200	0.473	0.292	0.001	0.195	0.245	0.340	0.208
C-G	4	0-45	30	1413	743	53%	**188**	**123**	**1245**	0.010	0.005	0.006	0.095	0.001	**24**	**32**	**706**	**819**
C-H	4	0-45	100	1500	1006	67%	**121**	**79**	**1076**	0.058	0.024	0.031	0.001	0.001	**129**	**49**	**249**	**693**
C-I	4	0-45	300	1376	533	39%	0.05	0.03	0.37	0.023	0.005	0.006	0.011	0.076	0.043	0.050	0.367	0.050
C-J	4	0-60	0	1430	605	42%	0.03	0.02	0.2	0.010	0.008	0.006	0.011	0.076	0.043	0.050	0.144	0.050
C-K	4	0-60	30	1341	452	34%	0.05	0.03	0.2	0.023	0.034	0.027	0.011	0.076	0.043	0.050	0.050	0.050
C-L	4	0-60	100	1374	495	36%	0.03	0.02	0.1	0.005	0.005	0.010	0.011	0.076	0.043	0.050	0.050	0.050
C-M	4	0-60	300	1378	445	32%	0.07	0.05	0.16	0.037	0.035	0.030	0.055	0.095	0.043	0.050	0.075	0.050

All samples were analyzed in the BIOE Laboratory.

LEACHING EXPERIMENT - RUN 2 - BACKGROUND NO3-N IN LEACHATE

Col.	Tailings from Site	Col. Length	Applic. Rate	NO3-N concentration Back-ground Jul. 31	Back-ground Aug. 5	Back-ground Aug. 12
		(cm)	(dt/ha)	(mg/L)	(mg/L)	(mg/L)
C1	3	0-90	0	0.001	0.001	0.001
C2	3	0-90	30	0.001	0.001	0.001
C3	3	0-90	100	0.001	0.002	0.004
C4	3	0-90	300	0.001	-	0.001
C5	3	0-90	300	0.013	0.011	0.006
C6	3	0-45	0	0.001	0.007	0.005
C7	3	0-45	30	0.001	-	0.002
C8	3	0-45	100	0.023	0.027	0.016
C9	3	0-45	300	0.005	0.006	0.004
C10	3	0-60	0	0.017	0.022	0.002
C11	3	0-60	30	0.001	-	0.002
C12	3	0-60	100	0.006	0.005	0.004
C13	3	0-60	300	0.002	-	0.002

All samples were analyzed in the BIOE Laboratory.

Col.	Tailings from Site	Col. Length	Applic. Rate	NO3-N concentration Back-ground Jul. 31	Back-ground Aug. 5	Back-ground Aug. 12
		(cm)	(dt/ha)	(mg/L)	(mg/L)	(mg/L)
C-A	4	0-90	0	0.011	0.005	0.006
C-B	4	0-90	30	0.166	0.157	0.173
C-C	4	0-90	100	0.007	0.005	0.181
C-D	4	0-90	300	0.097	0.028	0.048
C-E	4	0-90	300	0.205	0.130	0.143
C-F	4	0-45	0	0.024	1.200	0.473
C-G	4	0-45	30	0.010	0.005	0.006
C-H	4	0-45	100	0.058	0.024	0.031
C-I	4	0-45	300	0.023	0.005	0.006
C-J	4	0-60	0	0.010	0.008	0.006
C-K	4	0-60	30	0.023	0.034	0.027
C-L	4	0-60	100	0.005	0.005	0.010
C-M	4	0-60	300	0.037	0.035	0.030

LEACHING EXPERIMENT - RUN 2 (COLUMNS) - TKN - OVERVIEW

Class Level Information

Class	Levels	Values				
APPL	4	_ 0 dt/ha	_ 30 dt/ha	_100 dt/ha	_300 dt/ha	
LENGTH	3	_0-45 cm Col.		_0-60 cm Col.		_0-90 cm Col.

Number of observations in data set for Site 3 and Site 4 each = 13 (DF for Error = 1)

Notes:
In Leaching Run 2, the TKN leaching behaviour differed between the tailings from sites 3 and 4.
Therefore, a separate analysis was conducted on the data collected for these sites.

The factorial model with parameters APPL (application rate) and
LENGTH (col. length) was applied to the data.
'R-Square' refers to the R^2 of the model y = APPL | LENGTH in the statistical SAS procedure GLM.
The Duncan multiple range test at the 0.05 level of probability was used to determine significantly different means.
'Std. Dev. ' refers to the sample standard deviation.
'C.V.' refers to the coefficient of variation in percent.
'N' refers to the number of samples for average calculations.
Means preceded by different letters are significantly different.
If the concentration measured was below the detection limit, half the concentration of the
detection limit was used in calculations.

LEACHING RUN 2 - SITE 3		R-Square:	C.V.:	Std. Dev.:	Mean:		
Total TKN/Column	**(mg/col)**	0.982	18	0.06	0.35		
Max. TKN/Column	**(mg/L)**	0.995	13	0.28	2.16		
Week 1 - TKN	**(mg/L)**	APPL, LENGTH, and APPL*LENGTH sig., but all values				<	0.6
Week 2 - TKN	**(mg/L)**	0.987	14	0.06	0.40		
Week 3 - TKN	**(mg/L)**	APPL, LENGTH, and APPL*LENGTH sig., but all values				<	0.6
Week 4 - TKN	**(mg/L)**	APPL, LENGTH, and APPL*LENGTH sig., but all values				<	3.5
Week 5 - TKN	**(mg/L)**	all values				<	0.2
Week 8 - TKN	**(mg/L)**	0.918	77	0.58	0.75		
Week 9 - TKN	**(mg/L)**	0.988	28	0.09	0.32		
Week 12 - TKN	**(mg/L)**	0.763	60	0.06	0.09		

LEACHING RUN 2 - SITE 4		R-Square:	C.V.:	Std. Dev.:	Mean:		
Total TKN/Column	**(mg/col.)**	APPL, LENGTH, and APPL*LENGTH sig., but all values except for the Column C-H concentration				<	1.0
Max. TKN/Column	**(mg/L)**	APPL, LENGTH, and APPL*LENGTH sig., but all values except for the Column C-H concentration				<	5.6
Week 1 - TKN	**(mg/L)**	0.640	177	0.5	0.3		
Week 2 - TKN	**(mg/L)**	APPL, LENGTH, and APPL*LENGTH sig., but all values except for the Column C-H concentration				<	0.8
Week 3 - TKN	**(mg/L)**	APPL, LENGTH, and APPL*LENGTH sig., but all values except for the Column C-H concentration				<	0.2
Week 4 - TKN	**(mg/L)**	APPL, LENGTH, and APPL*LENGTH sig., but all values except for the Column C-H concentration				<	2.5
Week 5 - TKN	**(mg/L)**	all values				<	0.2
Week 8 - TKN	**(mg/L)**	APPL, LENGTH, and APPL*LENGTH sig., but all values except for the Column C-H concentration				<	5.6
Week 9 - TKN	**(mg/L)**	APPL, LENGTH, and APPL*LENGTH sig., but all values except for the Column C-H concentration				<	3.2
Week 12 - TKN	**(mg/L)**	0.992	63	0.3	0.4		

LEACHING EXPERIMENT - RUN 2 (COLUMNS) - TKN - OVERVIEW

TKN concentration for Column C-H:

		Column: Appl. Rate: Col. Length:	C-H 100 dt/ha 0-45 cm
Week 2 - TKN	(mg/L)		125
Week 3 - TKN	(mg/L)		155
Week 4 - TKN	(mg/L)		23
Week 8 - TKN	(mg/L)		10
Week 9 - TKN	(mg/L)		7

Mass of TKN in Leachate collected from Column H in Weeks with high TKN Concentrations:

		Column: Appl. Rate: Col. Length:	C-H 100 dt/ha 0-45 cm
Week 2 - TKN	(mg/col.)		81
Week 3 - TKN	(mg/col.)		47
Week 4 - TKN	(mg/col.)		1
Week 8 - TKN	(mg/col.)		1
Week 9 - TKN	(mg/col.)		1

LEACHING EXPERIMENT - RUN 2 (COLUMNS) - TKN IN LEACHATE

Col.	Tailings from Site	Col. Length	Applic. Rate	Total Leachate Water collected	Analyzed Leachate	Percent. of Leachate analyzed	Estimated mg TKN in Total Leachate	Estimated kg/ha TKN in Total Leachate	Maximum measured TKN Concentr.	Average weekly TKN concentration in leachate. Week 1 Aug. 16 -> 22	Week 2 Aug. 23 -> 29	Week 3 Aug. 30 -> Sep.	Week 4 Sep. 6 -> 12	Week 5 Sep. 13 -> 19	Week 8 Oct. 4 -> 10	Week 9 Oct. 11 -> 17	Week 12 Nov. 1 -> 7	Average TKN Conc.	Standard Dev.	C.V.
		(cm)	(dt/ha)	(mL)	(mL)	(%)	(mg/col.)	(kg/ha)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(%)
C1	3	0-90	0	1275	280	22.0%	0.23	0.15	0.80	< 0.20	0.28	< 0.20	< 0.20	< 0.20	0.61	0.20	< 0.20	0.2	0.2	100%
C2	3	0-90	30	1435	350	24.4%	0.37	0.24	1.50	< 0.20	0.58	< 0.20	< 0.20	< 0.20	0.96	0.78	< 0.20	0.4	0.4	100%
C3	3	0-90	100	1258	213	16.9%	0.34	0.22	1.20	< 0.20	0.49	0.64	< 0.20	< 0.20	0.45	0.46	< 0.20	0.3	0.2	67%
C4	3	0-90	300	1166	208	17.8%	0.19	0.12	1.60	< 0.20	0.40	< 0.20	< 0.20	< 0.20	0.35	< 0.20	< 0.20	0.2	0.1	50%
C5	3	0-90	300	1327	239	18.0%	0.28	0.18	1.20	< 0.20	0.32	< 0.20	< 0.20	< 0.20	1.17	0.23	< 0.20	0.3	0.4	133%
C6	3	0-45	0	1131	300	26.5%	0.27	0.18	2.60	< 0.20	0.33	< 0.20	1.34	-	1.30	0.52	-	0.6	0.6	100%
C7	3	0-45	30	1135	267	23.5%	0.64	0.42	4.40	< 0.20	0.33	< 0.20	3.45	-	-	0.66	-	0.9	1.2	133%
C8	3	0-45	100	1041	183	17.6%	0.38	0.25	2.40	0.39	0.31	< 0.20	1.27	< 0.20	-	< 0.20	-	0.4	0.4	100%
C9	3	0-45	300	954	206	21.6%	0.26	0.17	2.10	< 0.20	0.69	< 0.20	1.07	< 0.20	-	< 0.20	< 0.20	0.3	0.4	133%
C10	3	0-60	0	1339	322	24.0%	0.29	0.19	1.50	< 0.20	0.23	< 0.20	< 0.20	< 0.20	1.50	0.48	< 0.20	0.3	0.5	167%
C11	3	0-60	30	1279	195	15.2%	0.63	0.41	4.60	0.62	0.31	< 0.20	2.34	< 0.20	0.56	< 0.20	< 0.20	0.5	0.8	160%
C12	3	0-60	100	1343	243	18.1%	0.37	0.24	1.90	< 0.20	0.59	< 0.20	< 0.20	< 0.20	1.85	0.38	< 0.20	0.4	0.6	150%
C13	3	0-60	300	935	155	16.6%	0.35	0.23	2.30	0.52	0.33	< 0.20	1.18	< 0.20	0.91	< 0.20	< 0.20	0.4	0.4	100%
C-A	4	0-90	0	1481	494	33.4%	0.9	0.6	4.6	0.57	0.23	< 0.20	2.33	< 0.20	1.00	< 0.20	< 0.20	0.6	0.8	133%
C-B	4	0-90	30	1243	198	15.9%	0.6	0.4	4.3	0.18	0.18	< 0.20	2.20	< 0.20	0.73	0.45	0.72	0.6	0.7	117%
C-C	4	0-90	100	1464	300	20.5%	0.5	0.3	1.3	0.67	0.77	< 0.20	< 0.20	< 0.20	-	< 0.20	< 0.20	0.3	0.3	100%
C-D	4	0-90	300	1435	297	20.7%	0.3	0.2	1.4	< 0.20	0.68	< 0.20	< 0.20	< 0.20	-	< 0.20	0.43	0.2	0.2	100%
C-E	4	0-90	300	801	138	17.2%	0.2	0.1	0.9	0.87	0.34	< 0.20	< 0.20	< 0.20	-	< 0.20	-	0.3	0.3	100%
C-F	4	0-45	0	1527	623	40.8%	0.4	0.2	2.8	< 0.20	0.42	< 0.20	1.44	-	0.74	< 0.20	0.18	0.4	0.5	125%
C-G	4	0-45	30	1413	537	38.0%	1.0	0.6	5.6	0.43	0.43	< 0.20	1.24	-	5.60	3.22	< 0.20	1.6	2.0	125%
C-H	4	0-45	100	1500	705	47.0%	158	103	249	< 0.20	125	155	23	-	9.60	7.09	3.26	46.2	62.5	135%
C-I	4	0-45	300	1376	328	23.8%	0.5	0.3	1.4	0.26	0.68	< 0.20	< 0.20	< 0.20	1.14	0.73	0.30	0.4	0.4	100%
C-J	4	0-60	0	1430	332	23.2%	0.4	0.2	1.2	< 0.20	0.43	< 0.20	< 0.20	< 0.20	1.08	1.24	< 0.20	0.4	0.5	125%
C-K	4	0-60	30	1341	244	18.2%	0.3	0.2	1.3	< 0.20	0.43	< 0.20	< 0.20	< 0.20	1.34	0.36	-	0.4	0.4	100%
C-L	4	0-60	100	1374	281	20.5%	0.9	0.6	2.9	0.43	0.30	< 0.20	2.46	< 0.20	2.20	0.53	-	0.9	1.0	111%
C-M	4	0-60	300	1378	257	18.7%	0.5	0.3	2.2	< 0.20	0.22	< 0.20	1.16	< 0.20	1.47	0.32	< 0.20	0.4	0.5	125%

All samples were analyzed in the BIOE Laboratory.
In statistical calculations, half the concentration of the detection limit was used for sample concentrations below the detection limit.
'-' Not enough leachate was collected to be able to conduct a TKN analysis.
'Standard Dev.' refers to the sample standard deviation.
'C.V.' refers to the coefficient of variation in percent.

LEACHING EXPERIMENT - RUN 2 (COLUMNS) - TOTAL P (PO4-P) IN LEACHATE

Col.	Tailings from Site	Col. Length	Applic. Rate	Total Leachate Water collected	Analyzed Leachate	Percent. of Leachate analyzed	Estimated mg TOTAL P in Total Leachate	Estimated kg/ha TOTAL P in Total Leachate	Maximum measured TOTAL P Concentr.	Average weekly TOTAL P (PO4-P) concentration in leachate. Week 1 Aug. 16 -> 22	Week 2 Aug. 23 -> 29	Week 3 Aug. 30 -> Sep. 5	Week 4 Sep. 6 -> 12	Week 5 Sep. 13 -> 19	Week 8 Oct. 4 -> 10	Week 9 Oct. 11 -> 17	Week 12 Nov. 1 -> 7	Average Total P Conc.	Standard Dev.	C.V.
		(cm)	(dt/ha)	(mL)	(mL)	(%)	(mg/col.)	(kg/ha)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(%)
C1	3	0-90	0	1275	464	36.4%	0.04	0.03	0.22	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.22	< 0.01	0.03	0.08	267%
C2	3	0-90	30	1435	561	39.1%	0.02	0.01	0.04	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.04	< 0.01	0.01	0.01	100%
C3	3	0-90	100	1258	350	27.8%	0.02	0.01	0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.01	0.00	0%
C4	3	0-90	300	1166	362	31.0%	0.06	0.04	0.15	< 0.01	< 0.01	< 0.01	< 0.01	0.15	< 0.01	< 0.01	< 0.01	0.02	0.05	250%
C5	3	0-90	300	1327	408	30.7%	0.05	0.03	0.19	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.19	< 0.01	0.03	0.07	233%
C6	3	0-45	0	1131	519	45.9%	0.02	0.01	0.08	< 0.01	< 0.01	< 0.01	< 0.01	-	0.08	0.07	< 0.01	0.02	0.03	150%
C7	3	0-45	30	1135	478	42.1%	0.03	0.02	0.11	< 0.01	< 0.01	< 0.01	< 0.01	-	-	0.11	< 0.01	0.02	0.04	200%
C8	3	0-45	100	1041	343	32.9%	0.12	0.08	0.58	0.12	< 0.01	< 0.01	< 0.01	0.58	-	< 0.01	< 0.01	0.10	0.21	210%
C9	3	0-45	300	954	336	35.2%	0.04	0.03	0.19	< 0.01	< 0.01	< 0.01	0.19	< 0.01	< 0.01	0.09	< 0.01	0.04	0.07	175%
C10	3	0-60	0	1339	561	41.9%	0.04	0.03	0.37	< 0.01	< 0.01	< 0.01	< 0.01	0.37	< 0.01	0.24	< 0.01	0.08	0.14	175%
C11	3	0-60	30	1279	352	27.5%	0.03	0.02	0.13	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.13	< 0.01	0.02	0.04	200%
C12	3	0-60	100	1343	410	30.5%	0.04	0.02	0.20	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.20	< 0.01	0.03	0.07	233%
C13	3	0-60	300	935	270	28.9%	0.02	0.01	0.02	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.02	< 0.01	0.01	0.01	100%
C-A	4	0-90	0	1481	707	47.7%	0.03	0.02	0.21	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.21	-	0.03	0.08	267%
C-B	4	0-90	30	1243	354	28.5%	0.04	0.02	0.15	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.15	< 0.01	0.02	0.05	250%
C-C	4	0-90	100	1464	512	35.0%	0.03	0.02	0.13	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.13	< 0.01	0.02	0.04	200%
C-D	4	0-90	300	1435	480	33.4%	0.02	0.01	0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.01	0.00	0%
C-E	4	0-90	300	801	237	29.6%	0.02	0.01	0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	-	< 0.01	0.01	0.01	0.00	0%
C-F	4	0-45	0	1527	842	55.1%	0.04	0.03	0.28	< 0.01	< 0.01	< 0.01	< 0.01	-	0.28	-	< 0.01	0.05	0.11	220%
C-G	4	0-45	30	1413	743	52.6%	0.51	0.33	0.13	< 0.01	< 0.01	< 0.01	< 0.01	-	0.13	< 0.01	< 0.01	0.02	0.05	250%
C-H	4	0-45	100	1500	1006	67.1%	0.57	0.37	0.68	0.04	0.27	0.29	< 0.01	-	0.68	< 0.01	< 0.01	0.19	0.25	132%
C-I	4	0-45	300	1376	533	38.7%	0.02	0.01	0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.01	0.00	0%
C-J	4	0-60	0	1430	605	42.3%	0.03	0.02	0.06	0.06	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.01	0.02	400%
C-K	4	0-60	30	1341	452	33.7%	0.04	0.03	0.15	0.15	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.02	0.05	250%
C-L	4	0-60	100	1374	495	36.0%	0.02	0.01	0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.01	0.00	0%
C-M	4	0-60	300	1378	445	32.3%	0.02	0.01	0.01	< 0.01	< 0.01	< 0.01	< 0.01	-	< 0.01	< 0.01	< 0.01	0.01	0.00	0%

All samples were analyzed in the BIOE Laboratory.
In statistical calculations, half the concentration of the detection limit was used for sample concentrations below the detection limit.
'-' Not enough leachate was collected to be able to conduct a TOTAL P analysis.
'Standard Dev.' refers to the sample standard deviation.
'C.V.' refers to the coefficient of variation in percent.

LEACHING EXPERIMENT - RUN 2 (COLUMNS) - pH OF LEACHATE

Col.	Tailings from Site	Col. Length	Applic. Rate	pH of leachate Week 1	Week 2	Week 3	Week 4	Week 5	Week 8	Week 9	Week 12	Week 13	Average pH	Standard Dev.	C.V.
				Aug. 16 -> 22	Aug. 23 -> 29	Aug. 30 -> Sep. 5	Sep. 6 -> 12	Sep. 13 -> 19	Oct. 4 -> 10	Oct. 11 -> 17	Nov. 1 -> 7	Nov. 8 -> 14			
		(cm)	(dt/ha)												(%)
C1	3	0-90	0	n/a	8.0	8.0	8.0	7.9	7.7	7.9	7.8	7.7	7.9	0.1	1%
C2	3	0-90	30	n/a	8.0	7.9	8.1	7.9	7.7	7.9	7.8	7.8	7.9	0.1	1%
C3	3	0-90	100	n/a	8.1	8.0	8.1	8.0	7.8	8.0	7.9	8.2	8.0	0.1	1%
C4	3	0-90	300	n/a	8.1	8.0	8.0	7.9	7.8	7.9	7.8	7.9	7.9	0.1	1%
C5	3	0-90	300	n/a	8.0	8.0	8.0	7.9	7.8	7.9	7.9	8.0	7.9	0.1	1%
C6	3	0-45	0	n/a	8.0	7.9	8.2	-	8.0	7.9	7.9	7.9	8.0	0.1	1%
C7	3	0-45	30	n/a	8.0	8.1	8.2	-	-	8.1	8.2	8.2	8.1	0.1	1%
C8	3	0-45	100	n/a	8.1	8.0	8.3	8.3	-	8.3	8.4	8.4	8.2	0.1	1%
C9	3	0-45	300	n/a	8.1	8.2	8.3	-	8.2	8.3	8.4	8.1	8.2	0.1	1%
C10	3	0-60	0	n/a	8.0	8.0	8.0	7.8	7.9	7.9	8.0	8.0	7.9	0.1	1%
C11	3	0-60	30	n/a	8.1	8.0	8.0	7.9	8.0	8.0	8.0	8.0	8.0	0.0	0%
C12	3	0-60	100	n/a	8.1	8.0	8.1	8.0	8.0	8.2	8.2	8.5	8.1	0.2	2%
C13	3	0-60	300	n/a	8.0	8.0	8.1	7.9	7.9	8.1	8.1	8.2	8.0	0.1	1%
C-A	4	0-90	0	n/a	8.0	7.9	7.9	7.7	7.9	8.2	7.8	7.9	7.9	0.1	1%
C-B	4	0-90	30	n/a	8.1	8.0	8.0	7.8	7.9	8.1	8.0	7.9	8.0	0.1	1%
C-C	4	0-90	100	n/a	8.1	8.0	8.0	7.9	7.9	8.1	8.0	8.0	8.0	0.1	1%
C-D	4	0-90	300	n/a	8.1	8.0	8.0	7.9	8.0	7.9	8.0	8.1	8.0	0.1	1%
C-E	4	0-90	300	n/a	8.1	8.1	8.0	7.9	8.0	8.0	8.0	8.1	8.1	0.1	1%
C-F	4	0-45	0	n/a	8.0	8.0	8.0	-	7.8	-	7.7	7.8	7.9	0.2	3%
C-G	4	0-45	30	n/a	8.2	8.2	8.2	-	8.2	8.0	8.1	8.2	8.1	0.1	1%
C-H	4	0-45	100	n/a	7.8	8.0	8.2	-	7.5	7.6	7.6	7.7	7.8	0.3	4%
C-I	4	0-45	300	n/a	8.3	8.4	8.2	8.2	8.3	8.3	8.3	8.4	8.3	0.1	1%
C-J	4	0-60	0	n/a	8.1	8.0	8.0	7.8	7.9	7.8	8.0	8.1	8.0	0.1	1%
C-K	4	0-60	30	n/a	8.1	8.0	8.0	7.8	7.9	7.9	8.0	8.0	8.0	0.1	1%
C-L	4	0-60	100	n/a	8.1	8.1	8.0	7.9	7.8	7.9	8.0	8.1	8.0	0.1	1%
C-M	4	0-60	300	n/a	7.9	8.1	8.0	7.9	7.9	7.9	8.1	8.2	8.0	0.1	1%

All samples were analyzed in the BIOE Laboratory.
'Standard Dev.' refers to the sample standard deviation.
'C.V.' refers to the coefficient of variation in percent.
'-' Not enough leachate was collected to determine pH.

LEACHING EXPERIMENT - RUN 2 (COLUMNS) - ELECTRICAL CONDUCTIVITY OF LEACHATE

Col.	Tailings from Site	Col. Length	Applic. Rate	Electrical conductivity of leachate Week 1 Aug. 16 -> 22	Week 2 Aug. 23 -> 29	Week 3 Aug. 30 -> Sep. 5	Week 4 Sep. 6 -> 12	Week 5 Sep. 13 -> 19	Week 8 Oct. 4 -> 10	Week 9 Oct. 11 -> 17	Week 12 Nov. 1 -> 7	Week 13 Nov. 8 -> 14	Average Conc.	Standard Dev.	C.V.
		(cm)	(dt/ha)	(dS/m)	(dS/m)	(dS/m)	(dS/m)	(dS/m)	(dS/m)	(dS/m)	(dS/m)	(dS/m)	(dS/m)	(dS/m)	(%)
C1	3	0-90	0	1.00	1.10	1.00	1.00	1.10	1.10	1.00	1.00	1.10	1.0	0.1	5%
C2	3	0-90	30	1.00	1.00	1.00	1.10	1.10	1.00	1.00	1.00	1.00	1.0	0.0	2%
C3	3	0-90	100	1.00	1.10	1.20	1.10	1.00	1.00	1.00	1.10	1.10	1.1	0.1	7%
C4	3	0-90	300	1.00	1.00	1.00	1.10	1.00	1.00	1.00	1.00	1.10	1.0	0.0	4%
C5	3	0-90	300	1.10	1.00	1.00	1.10	1.10	1.00	1.00	1.00	1.10	1.0	0.1	5%
C6	3	0-45	0	0.70	0.70	0.70	0.60	-	-	0.70	0.60	0.60	0.6	0.1	9%
C7	3	0-45	30	0.70	0.60	0.80	0.70	-	-	0.80	0.80	0.80	0.7	0.1	9%
C8	3	0-45	100	0.70	0.60	0.60	0.70	0.70	-	0.70	0.80	0.80	0.7	0.1	11%
C9	3	0-45	300	0.70	0.60	0.70	0.70	0.80	-	0.80	0.90	0.80	0.7	0.1	12%
C10	3	0-60	0	1.00	1.00	0.90	0.80	0.80	0.80	0.80	0.80	0.80	0.8	0.1	8%
C11	3	0-60	30	1.00	1.00	1.00	1.00	0.80	0.90	0.80	0.80	0.80	0.9	0.1	9%
C12	3	0-60	100	1.00	1.00	0.90	0.90	0.80	0.80	0.70	0.80	0.90	0.9	0.1	13%
C13	3	0-60	300	1.00	1.00	1.00	1.00	0.80	0.90	1.00	1.00	1.00	1.0	0.1	9%
C-A	4	0-90	0	2.80	3.00	2.80	2.80	2.80	2.70	2.60	2.20	2.00	2.6	0.3	12%
C-B	4	0-90	30	1.80	3.10	2.90	2.90	2.90	2.80	2.80	2.80	2.70	2.7	0.4	14%
C-C	4	0-90	100	3.00	3.10	2.80	2.90	2.40	2.60	2.90	2.00	2.70	2.7	0.4	13%
C-D	4	0-90	300	2.90	3.10	3.00	3.00	2.40	2.80	2.90	-	3.00	2.9	0.2	7%
C-E	4	0-90	300	1.70	3.10	2.90	2.90	3.00	-	2.60	2.80	3.00	2.8	0.5	16%
C-F	4	0-45	0	2.20	2.40	2.50	1.90	-	-	-	0.90	1.00	1.8	0.7	38%
C-G	4	0-45	30	2.00	2.00	1.90	1.80	-	-	1.70	2.10	2.10	1.9	0.2	8%
C-H	4	0-45	100	1.90	4.80	3.40	1.70	-	-	-	1.10	1.30	2.4	1.5	61%
C-I	4	0-45	300	2.10	2.20	1.80	1.70	1.60	-	1.80	2.10	2.10	1.9	0.2	11%
C-J	4	0-60	0	2.70	2.80	2.60	2.50	2.40	2.40	2.20	2.10	2.00	2.4	0.3	11%
C-K	4	0-60	30	2.60	3.00	2.90	2.90	2.80	3.00	2.80	2.70	2.60	2.8	0.2	5%
C-L	4	0-60	100	2.50	2.60	2.70	2.60	2.50	2.40	2.40	2.30	2.30	2.5	0.2	6%
C-M	4	0-60	300	2.70	2.90	2.60	2.50	2.10	2.20	2.20	2.00	2.00	2.4	0.3	14%

All samples were analyzed in the BIOE Laboratory.
'Standard Dev.' refers to the sample standard deviation.
'C.V.' refers to the coefficient of variation in percent.
'-' Not enough leachate was collected to measure the electrical conductivity.

APPENDIX J

Bulk Density & Particle Size Distribution

PRINCETON DEMO. PROJECT - BULK DENSITY

FIELD EXPERIMENT:

Application Rate: * (dt/ha)	Site:	Date:	Depth: (cm)	Average Bulk Density/Site: (kg/m^3)
Background	P2a	Oct.92	15-30	1193
Background	P2b	Oct.92	15-30	1149
Background	P3a/3b	Oct.92	15-30	1313
Background	Control	Oct.92	15-30	1239
Background Average:		Oct.92	15-30	1231
Background Std. Dev.		Oct.92	15-30	70
Background CV:		Oct.92	15-30	5.7%
179	P3a	Sep.93	0-15	896
77	P2a	Sep.93	0-15	1206
77	P3b	Sep.93	0-15	1117
62	P2b	Sep.93	0-15	1185
0	Control	Sep.93	0-15	1363
179	P3a	Sep.93	15-30	1463
77	P2a	Sep.93	15-30	1349
77	P3b	Sep.93	15-30	1336
62	P2b	Sep.93	15-30	1232
0	Control	Sep.93	15-30	1324

* In October 1992, stored dewatered biosolids were applied to all sites except the northern one third portion of P2b. Land-dried biosolids were applied to that portion of P2b.

LABORATORY EXPERIMENT (RUN 2):

Column 1 -> 13	(P2a-R1 tailings)	1130 kg/m^3
Column A -> M	(P2b-R1 tailings)	1000 kg/m^3

PRINCETON DEMONSTRATION PROJECT - PARTICLE SIZE DISTRIBUTION

Site	Depth (cm)	% Sand	% Silt	% Clay	Percent Particles < 0.001 mm	Unified Soil Class. (Wagner 1957)	U.S.D.A. Texture Triangle Class.	Coefficient of Permeability (BS 8004:1986) (m/s)
Ctrl C4	**0-15**	14.3	56.3	29.5	17.2	ML or CL	SiL	1.5E-07 - 1.0E-10
P2a-R1	**0-15**	31.5	45.0	23.5	12.6	ML or CL	SiL	1.5E-07 - 1.0E-10
P2a-R1	**15-30**	3.5	53.8	42.7	28.3	ML or CL	SiC	1.5E-07 - 1.0E-10
P2a-R1	**30-45**	3.2	56.3	40.5	25.6	ML or CL	SiC	1.5E-07 - 1.0E-10
P2a-R1	**45-60**	3.0	56.8	40.2	26.9	ML or CL	SiC	1.5E-07 - 1.0E-10
P2a-R1	**60-75**	2.8	58.9	38.3	23.7	ML or CL	SiCL	1.5E-07 - 1.0E-10
P2a-R1	**75-90**	6.7	58.4	34.9	20.5	ML or CL	SiCL	1.5E-07 - 1.0E-10
P2b-R1	**0-15**	17.2	60.4	22.4	10.8	ML or CL	SiL	1.5E-07 - 1.0E-10
P2b-R1	**15-30**	2.1	60.6	37.3	21.9	ML or CL	SiCL	1.5E-07 - 1.0E-10
P2b-R1	**30-45**	1.4	53.1	45.6	27.8	ML or CL	SiC	1.5E-07 - 1.0E-10
P2b-R1	**45-60**	1.3	53.6	45.1	26.2	ML or CL	SiC	1.5E-07 - 1.0E-10
P2b-R1	**60-75**	0.7	47.1	52.2	33.5	ML or CL	SiC	1.5E-07 - 1.0E-10
P2b-R1	**75-90**	1.0	54.5	44.6	29.1	ML or CL	SiC	1.5E-07 - 1.0E-10
P3a-R1	**0-15**	30.3	63.0	6.7	3.7	ML or CL	SiL	8.2E-05 - 1.5E-07
P3a-R1	**15-30**	13.2	71.2	15.6	9.5	ML or CL	SiL	8.2E-05 - 1.5E-07
P3a-R1	**30-45**	8.2	76.9	14.9	9.7	ML or CL	SiL	8.2E-05 - 1.5E-07
P3a-R1	**45-60**	1.3	81.6	17.1	9.8	ML or CL	SiL	8.2E-05 - 1.5E-07
P3a-R1	**60-75**	0.5	59.6	39.9	22.3	ML or CL	SiCL	1.5E-07 - 1.0E-10
P3a-R1	**75-90**	5.1	63.3	31.5	19.2	ML or CL	SiCL	1.5E-07 - 1.0E-10
P3a-R3	**0-15**	19.1	76.6	4.3	n/a	ML or CL	Si	8.2E-05 - 1.5E-07
P3a-R3	**15-30**	3.5	80.2	16.3	14.6	ML or CL	SiL	8.2E-05 - 1.5E-07
P3a-R3	**30-45**	3.0	76.8	20.2	13.3	ML or CL	SiL	1.5E-07 - 1.0E-10
P3a-R3	**45-60**	1.7	82.8	15.5	9.0	ML or CL	SiL	8.2E-05 - 1.5E-07
P3a-R3	**60-75**	2.1	76.3	21.6	n/a	ML or CL	SiL	1.5E-07 - 1.0E-10
P3a-R3	**75-90**	0.4	64.0	35.6	n/a	ML or CL	SiCL	1.5E-07 - 1.0E-10
P3b-R2	**0-15**	9.4	66.9	23.7	13.4	ML or CL	SiL	1.5E-07 - 1.0E-10
P3b-R2	**15-30**	3.1	69.8	27.1	15.0	ML or CL	SiL	1.5E-07 - 1.0E-10
P3b-R2	**30-45**	1.6	69.6	28.8	13.4	ML or CL	SiL	1.5E-07 - 1.0E-10
P3b-R2	**45-60**	0.7	55.4	43.9	24.0	ML or CL	SiC	1.5E-07 - 1.0E-10
P3b-R2	**60-75**	1.3	57.3	41.4	25.3	ML or CL	SiC	1.5E-07 - 1.0E-10
P3b-R2	**75-90**	9.0	80.3	10.7	5.0	ML or CL	Si	8.2E-05 - 1.5E-07

Notes:

Sand particles: 0.050 - 2 mm
Silt particles: 0.002 - 0.05 mm
Clay particles: < 0.002 mm

ML — Inorganic silts
=> more than 50% of particles < 63 um; liquid limit < 50
=> silty or clayey sands with slight plasticity

CL — Inorganic clays
=> more than 50% of particles < 63 um; liquid limit < 50
=> silty or sandy clays of low plasticity

ML or CL — soil classification depends on plasticity chart

In the leaching experiments, 'Tailings from Sites 1, 2, 3, or 4' refers to tailings originating from the discrete sampling locations 'P3a-R1', 'P3a-R3', 'P2a-R1', or 'P2b-R1' in the field.

APPENDIX K

Field Experiment - Vegetation

PRINCETON DEMONSTRATION PROJECT - FOLIAGE QUALITY - OVERVIEW

Class	Levels	Values		
AAPPL	3	_ 0 dt/ha	_ 62 dt/ha	_ 77 dt/ha

Number of observations for Yield (incl. _179 dt/ha data) = 22 (DF for Error = 19)
Number of observations for all other parameters = 17 (DF for Error = 14)

1993 FOLIAGE QUALITY				LITERATURE VALUES:		
Element:		**Mean:**	**Std. Dev:**	**Normal C.:**	**Excessive C.:**	
Arsenic,	**mg/kg**	7.6	3.3			
Cadmium,	**mg/kg**	< 0.50			> 3	(3)
Chromium,	**mg/kg**	AAPPL sig.			> 2	(3)
Copper,	**mg/kg**	AAPPL sig.		5.0 - 20	> 20	(2,5)
Lead,	**mg/kg**	5.0	1.7		> 10	(3)
Mercury,	**mg/kg**	0.010	0.004			
Molybdenum,	**mg/kg**	AAPPL sig.		0.1 - ?		(6)
Nickel,	**mg/kg**	1.2	0.6	0.1 - 1	> 50	(3,4)
NO3-N,	**%**	AAPPL sig.				
Selenium,	**mg/kg**	0.19	0.08		> 4	(6)
Total N,	**%**	AAPPL sig.		1.5		(1)
Zinc,	**mg/kg**	30.5	7.8	25.0 - 150	> 400	(2)
Yield,	**dt/ha**	AAPPL sig.				

Notes:
The main effect model with parameter AAPPL (application rate) was used for the data analysis.
The Duncan multiple range test at the 0.05 level of probability was used to determine significantly different means.
'Std. Dev. ' refers to the sample standard deviation.
All samples were analyzed by Norwest Labs.

(1) Salisbury and Ross, 1991
(2) Mortvedt et al., 1972
(3) CAST, 1976; Melsted, 1973; Univ. of Georgia Coop Ext., 1979
(4) Tisdale et al., 1993
(5) Coker et al., 1982
(6) Walsh and Beaton, 1973

PRINCETON DEMO. PROJECT - FOLIAGE QUALITY - SIGNIFICANT PARAMETERS

Class	Levels	Values		
AAPPL	3	_ 0 dt/ha	_ 62 dt/ha	_ 77 dt/ha
Number of observations		= 17	(DF for Error = 14)	

1993 FOLIAGE QUALITY								LIT. VALUES:	
Element / Appl. rate:		_0 dt/ha		_62 dt/ha		_77 dt /ha		_179 dt /ha	Normal C.:	Excess. C.:
Chromium, mg/kg	3.0	a	1.8	b	1.8	b	not compared		> 2 (3)
Copper, mg/kg	68	a	23	b	21	b	not compared	5.0 - 20	> 20 (2,4)
Molybdenum, mg/kg	24	a	6	b	4	b	not compared	0.1 - ?	(5)
NO3-N, %	0.003	b	0.010	ab	0.039	a	not compared		
Total N, %	1.5	ab	1.2	b	2.0	a	not compared	1.5	(1)
Yield, dt/ha	0.2	b	4.3	a	5.5	a	0.6 b		

Notes:
The main effect AAPPL (application rate) was applied to the data.
The Duncan multiple range test at the 0.05 level of probability was used to determine significantly different means.
Means followed by different letters are significantly different.
All samples were analyzed by Norwest Labs.
Since only one out of five samples collected from site 3a (179 dt/ha) yielded enough vegetation for analysis, only its yield data was compared with the other sites.

(1) Salisbury and Ross, 1991
(2) Mortvedt et al., 1972
(3) CAST, 1976; Melsted, 1973; Univ. of Georgia Coop Ext., 1979
(4) Coker et al., 1982
(5) Walsh and Beaton, 1973

PRINCETON DEMO. PROJECT - VEGETATION - FIELD DATA

Vegetation Yield in July 1993

Plot	Application Rate: (dt/ha)	Vegetation	Site Yield (kg/ha)	Percent of Total Yield (%)
Ctrl Seeded	0	Weeds	61	75
Ctrl Seeded	0	Grasses	20	25
Ctrl Unseeded	0	Weeds	533	82
Ctrl Unseeded	0	Grasses	114	18
P2b	62	Fall Rye	903	33
P2b	62	Weeds	749	27
P2b	62	Grasses	744	27
P2b	62	Alfalfa	289	10
P2b	62	Hairy Vetch	85	3
P2a	77	Fall Rye	481	46
P2a	77	Grasses	305	29
P2a	77	Alfalfa	129	12
P2a	77	Weeds	103	10
P2a	77	Hairy Vetch	22	2
P3b	77	Fall Rye	941	66
P3b	77	Grasses	354	25
P3b	77	Alfalfa	58	4
P3b	77	Weeds	58	4
P3b	77	Hairy Vetch	12	1
P3a	179	Fall Rye	358	70
P3a	179	Grasses	99	19
P3a	179	Alfalfa	30	6
P3a	179	Weeds	18	4
P3a	179	Hairy Vetch	4	1

Total Yield and Legume Establishment in July 1993

Plot	Application Rate (dt/ha)	Total Yield (kg/ha)	Legume Contribution to Total Yield (%)
Ctrl Seeded	0	81	0
Ctrl Unseeded	0	648	0
P2b	62	2770	13
P2a	77	1039	15
P3b	77	1422	5
P3a	179	509	7

YIELDJ93.XLS

PRINCETON DEMONSTRATION PROJECT - VEGETATION - FIELD DATA

Plot 2a (Application Rate = 77dt/ha)										
Quality/Metal Uptake/Dry Yield (Sept. 93)										
Sample	1	2	3	4	5	Composite S. (sample 1-5)	High	Low	Average (1)	Std. dev.(2)
Total Nitrogen (TKN) (%)	1.6	2.3	1.8	2.0	1.7		2.3	1.6	1.9	0.26
Nitrate-N (%)	0.010	0.070	0.020	0.010	0.080		0.080	0.010	0.038	0.034
Arsenic (mg/kg)	3.2	6.3	6.5	5.2	7.3	5.9	7.3	3.2	5.7	1.6
Cadmium (mg/kg)	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	0.0
Chromium (mg/kg)	1.0	2.0	2.0	2.0	3.0	3.0	3.0	1.0	2.0	1.0
Copper (mg/kg)	15.0	26.0	24.0	21.0	33.0	28.0	33.0	15.0	23.8	6.6
Lead (mg/kg)	2.0	5.0	5.0	5.0	9.0	11.0	9.0	2.0	5.2	2.5
Mercury (mg/kg)	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.02	< 0.01	< 0.01	< 0.01	0.00
Molybdenum (mg/kg)	4.0	16.0	4.0	5.0	3.0	8.0	16.0	3.0	6.4	5.4
Nickel (mg/kg)	1.0	1.0	1.0	1.0	3.0	2.0	3.0	1.0	1.0	1.0
Selenium (mg/kg)	0.1	0.2	0.3	0.2	0.2	< 0.1	0.3	0.1	0.2	0.1
Zinc (mg/kg)	24.0	25.0	24.0	40.0	47.0	30.0	47.0	24.0	32.0	10.8
Dry yield (dt/ha)	7.6	3.0	5.5	3.5	6.1		7.6	3.0	5.1	1.9

Notes:
1. The average includes discrete samples only. If the sample concentration was less than the detection limit, half the detection limit was used to compute the average.
2. The standard deviation includes discrete samples only.

Discrete samples were collected on a pre-determined grid pattern (determined prior to visiting the site).
Samples were analyzed by Norwest Labs and the laboratory methodologies are included in Appendix O.

PRINCETON DEMONSTRATION PROJECT - VEGETATION - FIELD DATA

Plot 2b (Application Rate = 62dt/ha)										
Quality/Metal Uptake/Dry Yield (Sept. 93)										
Sample	**1**	**2**	**3**	**4**	**5**	**Composite S.**	**High**	**Low**	**Average (1)**	**Std. dev.(2)**
						(sample 1-5)				
Total Nitrogen (TKN) (%)	1.3	0.9	1.8	0.9	1.2		1.8	0.9	1.2	0.4
Nitrate-N (%)	0.009	0.004	0.030	0.003	0.002		0.030	0.002	0.010	0.012
Arsenic (mg/kg)	9.1	7.2	11.5	6.1	5.8	5.8	11.5	5.8	7.94	2.4
Cadmium (mg/kg)	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	0.0
Chromium (mg/kg)	2.0	1.0	2.0	2.0	2.0	2.0	2.0	1.0	2.0	0.0
Copper (mg/kg)	27.0	21.0	30.0	20.0	16.0	29.0	30.0	16.0	22.8	5.6
Lead (mg/kg)	5.0	3.0	5.0	3.0	5.0	10.0	5.0	3.0	4.2	1.1
Mercury (mg/kg)	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.00
Molybdenum (mg/kg)	4.0	5.0	3.0	3.0	7.0	6.0	7.0	3.0	4.4	1.7
Nickel (mg/kg)	1.0	1.0	1.0	1.0	1.0	2.0	1.0	1.0	1.0	0.0
Selenium (mg/kg)	0.1	0.2	0.2	0.3	0.2	< 0.1	0.3	0.1	0.2	0.1
Zinc (mg/kg)	31.0	21.0	29.0	22.0	23.0	30.0	31.0	21.0	25.2	4.5
Dry yield (dt/ha)	5.6	2.8	2.7	5.0	5.6		5.6	2.7	4.3	1.5

Notes:
1. The average includes discrete samples only. If the sample concentration was less than the detection limit, half the detection limit was used to compute the average.
2. The standard deviation includes discrete samples only.

Discrete samples were collected on a pre-determined grid pattern (determined prior to visiting the site).
Samples were analyzed by Norwest Labs and the laboratory methodologies are included in Appendix O.

PRINCETON DEMONSTRATION PROJECT - VEGETATION - FIELD DATA

Plot 3a (Application Rate = 179 dt/ha								
Quality/Metal Uptake/Dry Yield (Sept. 93)								
Sample	**1**	**2**	**3**	**4**	**5**	**Composite S. (sample 1-5)**	**High***	**Low***
Total Nitrogen (TKN) (%)			2.6					
Nitrate-N (%)			0.03					
Arsenic (mg/kg)			5.9					
Cadmium (mg/kg)			< 0.5					
Chromium (mg/kg)			4.0					
Copper (mg/kg)			56.0					
Lead (mg/kg)			14.0					
Mercury (mg/kg)			0.2					
Molybdenum (mg/kg)			7.0					
Nickel (mg/kg)			3.0					
Selenium (mg/kg)			< 0.1					
Zinc (mg/kg)			59.0					
Dry yield (dt/ha)	0.0	0.0	3.2	0.0	0.0		8.3	0.2

Notes:
* The areas in the plot that appeared to have the thickest growth or the (average) least growth were sampled to provide a high/low estimate in yield. High and low growth locations were chosen visually on site 3a.
Discrete samples were collected on a pre-determined grid pattern (determined prior to visiting the site).
Samples were analyzed by Norwest Labs and the laboratory methodologies are included in Appendix O.

PRINCETON DEMONSTRATION PROJECT - VEGETATION - FIELD DATA

Plot 3b (Application Rate = 77dt/ha)										
Quality/Metal Uptake/Dry Yield (Sept. 93)										
Sample	1	2	3	4	5	Composite S. (sample 1-5)	High	Low	Average (1)	Std. dev.(2)
Total Nitrogen (TKN) (%)	2.0	1.8	2.0	1.7	2.7		2.7	1.7	2.0	0.4
Nitrate-N (%)	0.030	0.060	0.060	0.020	0.030		0.060	0.020	0.040	0.019
Arsenic (mg/kg)	3.8	11.5	10.4	8.7	14.5	4.1	14.5	3.8	9.78	4.0
Cadmium (mg/kg)	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	< 0.5	0.0
Chromium (mg/kg)	2.0	2.0	2.0	1.0	1.0	1.0	2.0	1.0	2.0	1.0
Copper (mg/kg)	18.0	20.0	23.0	12.0	20.0	23.0	23.0	12.0	18.6	4.1
Lead (mg/kg)	5.0	6.0	7.0	3.0	7.0	6.0	7.0	3.0	5.6	1.7
Mercury (mg/kg)	< 0.01	< 0.01	< 0.01	< 0.01	< 0.01	0.02	< 0.01	< 0.01	< 0.01	0.00
Molybdenum (mg/kg)	5.0	4.0	5.0	5.0	6.0	6.0	6.0	4.0	5.0	0.7
Nickel (mg/kg)	< 1.0	2.0	1.0	1.0	1.0	1.0	2.0	1.0	1.0	0.0
Selenium (mg/kg)	0.2	0.3	0.1	0.2	0.2	0.2	0.3	0.1	0.2	0.1
Zinc (mg/kg)	42.0	26.0	42.0	44.0	36.0	43.0	44.0	26.0	38.0	7.3
Dry yield (dt/ha)	5.2	9.8	3.8	9.8	1.0	5.6	9.8	1.0	5.9	3.8

Notes:
1. The average includes discrete samples only. If the sample concentration was less than the detection limit, half the detection limit was used to compute the average.
2. The standard deviation includes discrete samples only.

Discrete samples were collected on a pre-determined grid pattern (determined prior to visiting the site).
Samples were analyzed by Norwest Labs and the laboratory methodologies are included in Appendix O.

PRINCETON DEMONSTRATION PROJECT - VEGETATION - FIELD DATA

Seeded & Unseeded Control Plots (Appl. Rate = 0 dt/ha)		
Quality/Metal Uptake/Dry Yield (Sept. 93)		
	Seeded control	Unseeded control
Sample	1	1
Total Nitrogen (TKN) (%)	2.0	1.0
Nitrate-N (%)	0.002	0.003
Arsenic (mg/kg)	5.7	5.2
Cadmium (mg/kg)	< 0.5	< 0.5
Chromium (mg/kg)	3.0	3.0
Copper (mg/kg)	58.0	78.0
Lead (mg/kg)	6.0	4.0
Mercury (mg/kg)	0.04	0.02
Molybdenum (mg/kg)	43.0	5.0
Nickel (mg/kg)	1.0	1.0
Selenium (mg/kg)	< 0.1	0.3
Zinc (mg/kg)	23.0	19.0
Dry yield (dt/ha)	0.1	0.3

Notes:
The Total Nitrogen and Nitrate-N concentrations are the averages of three discrete samples.
Metal concentrations were determined from one composite sample which was made up of three subsamples.
Samples were analyzed by Norwest Lab. Refer to Appendix O for laboratory methodologies.

PRINCETON DEMO. PROJECT - VEGETATION - LONG FORM OF DATA ANALYSIS

Class	Levels	Values		
AAPPL	3	_ 0 dt/ha	_ 62 dt/ha	_ 77 dt/ha

Number of observations for Yield (incl. _179 dt/ha data)	= 22	(DF for Error = 19)
Number of observations for all other parameters	= 17	(DF for Error = 14)

Notes:
The main effect AAPPL (application rate) was examined.
'R-Square' refers to the R^2 of the 'model y = AAPPL' in the statistical SAS procedure GLM.
The Duncan multiple range test at the 0.05 level of probability was used
to determine significantly different means.
'Std. Dev. ' refers to the sample standard deviation.
'C.V.' refers to the coefficient of variation in percent.
'N' refers to the number of samples used in average calculations.
Means preceded by different letters are significantly different.
All samples were analyzed by Norwest Labs.

Element:		**R-Square:**	**C.V.:**	**Std. Dev:**	**Mean:**
Arsenic,	**mg/kg**	0.062	43.4	3.3	7.6
Cadmium,	**mg/kg**	all values			< 0.50
Chromium		AAPPL sig.			
Copper		AAPPL sig.			
Lead,	**mg/kg**	0.1	35.1	1.7	5.0
Mercury,	**mg/kg**	0.779	30.6	0.004	0.01
Molybdenum		AAPPL sig.			
Nickel,	**mg/kg**	0.053	50.1	0.57	1.2
NO3-N		AAPPL sig.			
Selenium,	**mg/kg**	0.005	41.1	0.08	0.2
Total N		AAPPL sig.			
Zinc,	**mg/kg**	0.378	25.7	7.8	30.5
Yield,	**dt/ha**	AAPPL sig.			

Chromium, mg/kg:

Duncan Grouping	Mean	N	AAPPL
A	3.0	2	_ 0 dt/ha
B	1.8	5	_ 62 dt/ha
B	1.8	10	_ 77 dt/ha

Copper, mg/kg:

Duncan Grouping	Mean	N	AAPPL
A	68.0	2	_ 0 dt/ha
B	22.8	5	_ 62 dt/ha
B	21.2	10	_ 77 dt/ha

Molybdenum (Mo), mg/kg:

Duncan Grouping	Mean	N	AAPPL
A	24.0	2	_ 0 dt/ha
B	5.7	10	_ 77 dt/ha
B	4.4	5	_ 62 dt/ha

PRINCETON DEMO. PROJECT - VEGETATION - LONG FORM OF DATA ANALYSIS

NO3-N, %:

Duncan Grouping		Mean	N	AAPPL
A		0.039	10	_ 77 dt/ha
B	A	0.010	5	_ 62 dt/ha
B		0.003	2	_ 0 dt/ha

Total N, %:

Duncan Grouping		Mean	N	AAPPL
A		2.0	10	_ 77 dt/ha
B	A	1.5	2	_ 0 dt/ha
B		1.2	5	_ 62 dt/ha

Yield, dry tonne/ha:

Duncan Grouping	Mean	N	AAPPL
A	5.5	10	_ 77 dt/ha
A	4.3	5	_ 62 dt/ha
B	0.6	5	_179 dt/ha
B	0.2	2	_ 0 dt/ha

APPENDIX L

Field Experiment - Soil Fertility

PRINCETON DEMO. PROJECT - SOIL FERTILITY - OVERVIEW TABLE

Class Level Information

Class	Level	Values			
Class Levels for the CEC Analysis:					
TIME	2	_Oct. 1992	_Apr. 1993		
AAPPL	4	_ 0 dt/ha	_ 62 dt/ha	_ 77 dt/ha	_179 dt/ha
Number of observations for CEC				= 9	(DF for Error = 1)
Class Levels for all other parameters:					
TIME	3	_Oct. 1992	_Apr. 1993	_Sep. 1993	
AAPPL	4	_ 0 dt/ha	_ 62 dt/ha	_ 77 dt/ha	_179 dt/ha
Number of observations for NH4-N and NO3-N				= 28	(DF for Error = 16)
Number of observations for all other parameters (except CEC)				= 13	(DF for Error = 1)

NUTRIENTS IN THE 0 - 15 cm Layer				LITERATURE VALUES	
		Mean:	Std. Dev.:	Low:	Normal Range:
pH		TIME sig.			
EC,	dS/m	1.5	0.9		
Boron		TIME sig.		< 0.5	0.5 (4)
Bray P-1		TIME and AAPPL sig.		< 7	7 - 20 (1)
Calcium		AAPPL sig.			30 - 300 (2)
CEC,	cmol/kg	7.3	1.3		
Copper		TIME and TIME*AAPPL sig.		< 0.2	(3)
Iron		TIME and AAPPL sig.		< 4.5	(3)
Magnesium,	mg/kg	182	18.1		5 - 50 (2)
Manganese,	mg/kg	4.8	2.2	< 1.0	(3)
NH4-N		TIME and TIME*AAPPL sig.			
NO3-N		TIME and TIME*AAPPL sig.			
%Organic Matter		1.3	1.3		
Potassium,	mg/kg	263	53	< 40	40 - 600 (2)
Sulfate,	mg/kg	224	102	< 5	5 (2)
Zinc,	mg/kg	9.6	8.3	< 0.8	(3)

Notes:

The data analysis is based on results for samples analyzed by Norwest Labs for all parameters except ammonia and nitrate.

The ammonia and nitrate data used in the analysis is included in this appendix (Norwest Labs - soil fertility data) and in Appendix M (GVRD Lab - soil nitrogen data).

The factorial model was used with the parameters AAPPL (application rate) and TIME (time).

The Duncan multiple range test at the 0.05 level of probability was used to determine significantly different means.

'Std. Dev. ' refers to the sample standard deviation.

(1) Page et al., 1982

(2) Tisdale et al., 1983

(3) Lindsay and Norvell, 1978 (critical levels for corn)

(4) Walsh and Beaton, 1973

PRINCETON DEMO. PROJECT - SOIL FERTILITY - SIG. PARAMETERS

Class Level Information

Class	Level	Values			
Class Levels for the CEC Analysis:					
TIME	2	_Oct. 1992	_Apr. 1993		
AAPPL	4	_ 0 dt/ha	_ 62 dt/ha	_ 77 dt/ha	_179 dt/ha

Number of observations for CEC = 9 (DF for Error = 1)

Class	Level	Values			
Class Levels for all other parameters:					
TIME	3	_Oct. 1992	_Apr. 1993	_Sep. 1993	
AAPPL	4	_ 0 dt/ha	_ 62 dt/ha	_ 77 dt/ha	_179 dt/ha

Number of observations for NH3-N and NO3-N = 28 (DF for Error = 16)
Number of observations for all other parameters (except CEC) = 13 (DF for Error = 1)

NUTRIENTS IN THE 0 - 15 cm LAYER				LITERATURE VALUES:	
Parameter/Time:	Oct. 1992	Apr. 1993	Sept. 1993	Low	Normal Range
pH	8.2 a	8.2 a	7.5 b		
Boron, mg/kg	0.6 a	0.7 a	0.2 b	< 0.5	0.5 (4)
Bray P-1, mg/kg *	1.6 b	45 a	51 a	< 7.0	7 - 20 (1)
Calcium, mg/kg *	3411 c	4116 b	4638 a		30 - 300 (2)
Iron, mg/kg *	38 b	63 b	168 a	< 4.5	(3)

* The concentration of the nutrient is also dependent on the application rate.

NUTRIENTS IN THE 0 - 15 cm LAYER					LIT. VALUES:	
Parameter/Appl. rate:	0 dt/ha	62 dt/ha	77 dt/ha	179 dt/ha	Low	Normal Range
Bray P-1, mg/kg **	3 b	4 b	22 b	83 a	< 7.0	7 - 20 (1)
Calcium, mg/kg **	5016 a	4605 a	3851 b	3376 b		30 - 300 (2)
Iron, mg/kg **	28 b	75 ab	96 a	95 a	< 4.5	(3)

** The concentration of the nutrient is also dependent on time.

Notes:
The data analysis is based on results for samples analyzed by Norwest Labs for all parameters except ammonia and nitrate.
The ammonia and nitrate data used in the analysis is included in this appendix (Norwest Labs - soil fertility data) and in Appendix M (GVRD Lab - soil nitrogen data).
The factorial model was used with the parameters AAPPL (application rate) and TIME (time).
The Duncan multiple range test at the 0.05 level of probability was used to determine significantly different means.
'Std. Dev. ' refers to the sample standard deviation.

(1) Page et al., 1982
(2) Tisdale et al., 1983
(3) Lindsay and Norvell, 1978 (critical levels for corn)
(4) Walsh and Beaton, 1973

PRINCETON DEMO. PROJECT - SOIL FERTILITY - SIG. PARAMETERS

NUTRIENTS IN THE 0 - 15 cm Layer:

NH4-N, mg/kg:

Level of TIME	Level of AAPPL	N	NH4-N Mean	SD
_Oct. 1992	_ 0 dt/ha	2	3.2	2.5
_Oct. 1992	_62 dt/ha	2	0.5	0.7
_Oct. 1992	_77 dt/ha	4	1.3	0.9
_Oct. 1992	_179 dt/ha	2	0.6	0.6
_Apr. 1993	_62 dt/ha	2	53	20
_Apr. 1993	_77 dt/ha	4	266	182
_Apr. 1993	_179 dt/ha	2	596	352
_Sep. 1993	_62 dt/ha	2	5.7	7.6
_Sep. 1993	_77 dt/ha	4	7.2	6.8
_Sep. 1993	_179 dt/ha	2	10.6	7.6

NO3-N, mg/kg:

Level of TIME	Level of AAPPL	N	NO3-N Mean	SD
_Oct. 1992	_ 0 dt/ha	2	1.7	1.9
_Oct. 1992	_62 dt/ha	2	1.0	1.4
_Oct. 1992	_77 dt/ha	4	1.1	1.1
_Oct. 1992	_179 dt/ha	2	1.0	1.4
_Apr. 1993	_62 dt/ha	2	2.5	0.8
_Apr. 1993	_77 dt/ha	4	4.8	6.2
_Apr. 1993	_179 dt/ha	2	3.6	2.3
_Sep. 1993	_62 dt/ha	2	4.9	3.0
_Sep. 1993	_77 dt/ha	4	126	44.2
_Sep. 1993	_179 dt/ha	2	297	6.4

Copper, mg/kg:

Level of TIME	Level of AAPPL	N	Copper Mean	SD
_Oct. 1992	_ 0 dt/ha	1	70	.
_Oct. 1992	_62 dt/ha	1	75	.
_Oct. 1992	_77 dt/ha	2	73	3.5
_Oct. 1992	_179 dt/ha	1	75	.
_Apr. 1993	_62 dt/ha	1	72	.
_Apr. 1993	_77 dt/ha	2	100	5.7
_Apr. 1993	_179 dt/ha	1	121	.
_Sep. 1993	_62 dt/ha	1	92	.
_Sep. 1993	_77 dt/ha	2	111	4.9
_Sep. 1993	_179 dt/ha	1	79	.

where N = number of samples analyzed; SD = Std. Dev.

PRINCETON DEMONSTRATION PROJECT - SOIL FERTILITY - FIELD DATA (0-15 cm)

Site	Control	Plot 2a			Plot 2b		
Application Rate (dt/ha)	0	77			62		
Parameter	Pre	Pre	Post-1	Post-2	Pre	Post-1	Post-2
	Oct-92	Oct-92	Apr-93	Sep-93	Oct-92	Apr-93	Sep-93
pH	7.7	8.6	8.3	7.6	8.0	8.1	7.7
EC (dS/m)	1.4	0.3	0.9	2.2	0.9	2.2	2.8
% Organic matter	0.1	0.1	0.6	0.8	0.1	0.1	0.9
CEC (cmol/kg)	6.6	6.9	6.2		6.9	9	
Ammonium (mg/kg)	5	1	106	13	1	39	11
Nitrate (mg/kg)	3	2	3	94	2	3	7
Phosphate (mg/kg)	3	1	9	31	2	1	9
Potassium (mg/kg)	298	298	301	224	368	271	260
Sulfate (mg/kg)	228	18	273	277	154	-	387
Calcium (mg/kg)	5016	3017	4004	4262	3129	5542	5144
Magnesium (mg/kg)	177	158	250	171	162	191	203
Iron (mg/kg)	28	43	38	183	47	26	153
Copper (mg/kg)	70	75	96	107	75	72	92
Zinc (mg/kg)	2.3	0.5	5.6	9.1	0.5	0.6	3.1
Boron (mg/kg)	0.9	0.5	0.7	0.2	0.4	0.4	0.2
Manganese (mg/kg)	6	2	4	3	3	1	2

Notes:

All samples were analyzed by Norwest Labs and the methods of extraction are described in Appendix O.

Pre samples were taken prior to biosolids application (early October 1992).

Post-1 samples were taken 6 months after biosolids application (April 1993).

Post-2 samples were taken 12 months after biosolids application (September 1993).

Application rates are reported in dt/ha (dry tonne/hectare).

PRINCETON DEMONSTRATION PROJECT - SOIL FERTILITY - FIELD DATA (0-15 cm)

Site	Plot 3a			Plot 3b		
Application Rate (dt/ha)	179			77		
Parameter	Pre	Post-1	Post-2	Pre	Post-1	Post-2
	Oct-92	Apr-93	Sep-93	Oct-92	Apr-93	Sep-93
pH	8.6	8.2	7.3	8.1	8.2	7.4
EC (dS/m)	0.3	2.2	3.6	1.2	1.3	0.3
% Organic matter	0.0	6.1	2.4	0.0	3.6	2.1
CEC (cmol/kg)	5.6	7.5		8.6	8.1	
Ammonium (mg/kg)	1	845	16	1	528	13
Nitrate (mg/kg)	2	2	292	2	2	170
Phosphate (mg/kg)	1	132	115	1	38	50
Potassium (mg/kg)	213	158	167	401	225	239
Sulfate (mg/kg)	18	484	334	369	55	375
Calcium (mg/kg)	2729	3064	4336	3164	3854	4810
Magnesium (mg/kg)	186	189	133	172	208	172
Iron (mg/kg)	30	116	138	41	73	198
Copper (mg/kg)	75	121	79	70	104	114
Zinc (mg/kg)	0.5	45	15	0.4	24	18
Boron (mg/kg)	0.5	0.9	0.2	0.8	0.8	0.3
Manganese (mg/kg)	2	15	8	2	9	5

Notes:

All samples were analyzed by Norwest Labs and the methods of extraction are described in Appendix O.

Pre samples were taken prior to biosolids application (early October 1992).

Post-1 samples were taken 6 months after biosolids application (April 1993).

Post-2 samples were taken 12 months after biosolids application (September 1993).

Application rates are reported in dt/ha (dry tonne/hectare).

PRINCETON DEMO. PROJECT - SOIL FERTILITY - FIELD DATA (0-15 cm)

COMPARISON OF AVAILABLE P (6 MONTHS AFTER BIOSOLIDS APPLICATION)

Plot:	Appl. Rate: (dt/ha)	Layer: (cm)	Date:	Bray P-1 (1:10 w/v) for Composite Samples (mg/kg)	Olsen-P Average of 3 Discrete Samples (mg/kg)
Control	0	0-15	Apr. 93	n/a	1
P2b	62	0-15	Apr. 93	1	7
P2a	77	0-15	Apr. 93	9	6
P3b	77	0-15	Apr. 93	38	15
P3a	179	0-15	Apr. 93	132	13

LITERATURE VALUES:

P Sufficiency Level	Bray P-1 * (1:7 w/v) (mg/kg)	Olsen P * (mg/kg)	Fertilizer P ** Recommendation (kg P/ha)
very low	< 3		25
low	3 - 7	< 5	15
medium	7 - 20	5 - 10	8
high	> 20	> 10	0

Notes:

Bray P-1 and Olsen-P concentrations were determined by Norwest Labs and the BIOE Lab respectively.

* Page et al. (1982)

** Tisdale et al. (1993)

PRINCETON DEMO. PROJECT - SOIL FERTILITY - LONG FORM OF DATA ANALYSIS

Class Level Information

Class	Level	Values			
Class Levels for the CEC Analysis:					
TIME	2	_Oct. 1992		_Apr. 1993	
AAPPL	4	_ 0 dt/ha	_ 62 dt/ha	_ 77 dt/ha	_179 dt/ha

Number of observations for CEC = 9 (DF for Error = 1)

Class	Level	Values				
Class Levels for all other parameters:						
TIME	3	_Oct. 1992		_Apr. 1993		_Sep. 1993
AAPPL	4	_ 0 dt/ha	_ 62 dt/ha	_ 77 dt/ha	_179 dt/ha	

Number of observations for NH4-N and NO3-N = 28 (DF for Error = 16)
Number of observations for all other parameters (except CEC) = 13 (DF for Error = 1)

Notes:
The data analysis is based on results for samples analyzed by Norwest Labs for all parameters except ammonia and nitrate.
The ammonia and nitrate data used in the analysis is included in this appendix (Norwest Labs - soil fertility data) and in Appendix M (GVRD Lab - soil nitrogen data).
The factorial model was used with the parameters AAPPL (application rate) and TIME (time).
The Duncan multiple range test at the 0.05 level of probability was used to determine significantly different means.
'R-Square' refers to the R^2 of the 'model y = TIME|AAPPL' in the statistical SAS procedure GLM.
'C.V.' refers to the coefficient of variation in percent.
'Std. Dev. ' refers to the sample standard deviation.
'N' refers to the number of samples for average calculations.
Means preceded by different letters are significantly different.

0-15 cm Layer:		R-Square:	C.V.:	Std. Dev.:	Mean:
pH		TIME sig.			
EC,	dS/m	0.820	58	0.9	1.5
Boron		TIME sig.			
Bray P-1		TIME and AAPPL sig.			
Calcium		AAPPL sig.			
CEC,	cmol/kg	0.680	18	1.3	7.3
Copper		TIME and TIME*AAPPL sig.			
Iron		TIME sig.			
Magnesium,	mg/kg	0.898	10	18.1	182
Manganese,	mg/kg	0.922	46	2.2	4.8
NH4-N		TIME and TIME*AAPPL sig.			
NO3-N		TIME and TIME*AAPPL sig.			
%Organic Matter		0.865	102	1.3	1.3
Potassium,	mg/kg	0.862	20	53	263
Sulfate,	mg/kg	0.886	45	102	224
Zinc,	mg/kg	0.900	87	8.3	9.6

PRINCETON DEMO. PROJECT - SOIL FERTILITY - LONG FORM OF DATA ANALYSIS

pH:

Duncan Grouping	Mean	N	TIME
A	8.2	4	_Apr. 1993
A	8.2	5	_Oct. 1992
B	7.5	4	_Sep. 1993

Boron, mg/kg:

Duncan Grouping	Mean	N	TIME
A	0.7	4	_Apr. 1993
A	0.6	5	_Oct. 1992
B	0.2	4	_Sep. 1993

Bray P-1, mg/kg:

Duncan Grouping	Mean	N	TIME
A	51.3	4	_Sep. 1993
A	45.0	4	_Apr. 1993
B	1.6	5	_Oct. 1992

Duncan Grouping	Mean	N	AAPPL
A	83	3	_179 dt/ha
B	22	6	_ 77 dt/ha
B	4	3	_ 62 dt/ha
B	3	1	_ 0 dt/ha

Calcium, mg/kg:

Duncan Grouping	Mean	N	TIME
A	4638	4	_Sep. 1993
B	4116	4	_Apr. 1993
C	3411	5	_Oct. 1992

Duncan Grouping	Mean	N	AAPPL
A	5016	1	_ 0 dt/ha
A	4605	3	_ 62 dt/ha
B	3852	6	_ 77 dt/ha
B	3376	3	_179 dt/ha

Iron, mg/kg:

Duncan Grouping	Mean	N	TIME
A	168	4	_Sep. 1993
B	63	4	_Apr. 1993
B	38	5	_Oct. 1992

Duncan Grouping	Mean	N	AAPPL
A	96	6	77 dt/ha
A	95	3	_179 dt/ha
B A	75	3	_ 62 dt/ha
B	28	1	_ 0 dt/ha

APPENDIX M

Field Experiment - Soil Nitrogen and Total Phosphorus

PRINCETON DEMO. PROJECT - NITROGEN & TP - OVERVIEW

Class Level Information

Class	Levels	Values		
TIME	3	_Oct. 1992	_Apr. 1993	_Sep. 1993
AAPPL	3	_ 62 dt/ha	_ 77 dt/ha	_179 dt/ha

Number of observations in data set = 12 (DF for Error = 3)

DEPTH		GVRD TKN (mg/kg)	GVRD NO3-N (mg/kg)	GVRD NH4-N (mg/kg)	GVRD TOTAL P (mg/kg)
0 - 15 cm	Mean	TIME sig.	TIME sig.	TIME	TIME sig.
				AAPPL, and	
				TIME* AAPPL	
				sig.	
15 - 30 cm	Mean	102	11.5	9.7	TIME and
	Std. Dev.	49	19.2	25.5	AAPPL sig.
30 - 60 cm	Mean	54	1.1	0.4	1577
	Std. Dev.	35	1.5	0.3	180
60 - 90 cm	Mean	56	TIME sig.	0.2	1530
	Std. Dev.	11		0.1	217
90 - 120 cm	Mean	55	TIME sig.	0.2	1637
	Std. Dev.	18		0.2	167
120 - 150 cm	Mean	57	TIME,	0.2	1541
	Std. Dev.	14	AAPPL and	0.3	132
			TIME*AAPPL		
			sig.		

Notes:
All samples were analyzed by the GVRD Lab using laboratory methods described in Appendix O.
The factorial model was used with the parameters AAPPL (application rate) and TIME (time).
The Duncan multiple range test at the 0.05 level of probability was used to determine significantly different means.
'Std. Dev. ' refers to the sample standard deviation.
TIME sig.' or 'AAPPL sig.' refers to significantly different means with respect to time or application rate.

PRINCETON DEMO. PROJECT - NITROGEN & TP - SIG. PARAMETERS

Class Level Information

Class	Levels	Values		
TIME	3	_Oct. 1992	_Apr. 1993	_Sep. 1993
AAPPL	3	_ 62 dt/ha	_ 77 dt/ha	_179 dt/ha

Number of observations in data set = 12 (DF for Error = 3)

Notes:
All samples were analyzed by the GVRD Lab using laboratory methods described in Appendix O.
The factorial model was used with the parameters AAPPL (application rate) and TIME (time).
The Duncan multiple range test at the 0.05 level of probability was used to determine significantly different means.
Means followed by different letters are significantly different.
'TIME sig.' or 'AAPPL sig.' refers to significantly different means with respect to time or application rate. 'TIME*AAPPL sig.' refers to a significant interaction term.
'N' refers to the number of samples for average calculations.
'Std. Dev. ' refers to the sample standard deviation.

TKN (mg/kg)			
Depth\Time:	Oct. 1992	Apr. 1993	Sept. 1993
0 - 15 cm	65 b	861 a	1254 a
15 - 30 cm	average for all times:		102
30 - 60 cm	average for all times:		54
60 - 90 cm	average for all times:		56
90 - 120 cm	average for all times:		55
120 - 150 cm	average for all times:		57

NO3-N (mg/kg)			
Depth\Time:	Oct. 1992	Apr. 1993	Sept. 1993
0 - 15 cm	0.2 b	5.4 b	136 a
15 - 30 cm	average for all times:		11.5
30 - 60 cm	average for all times:		1.1
60 - 90 cm	0.1 b	0.3 ab	0.5 a
90 - 120 cm	0.1 b	0.3 ab	0.5 a
120 - 150 cm *	TIME, AAPPL, and TIME*AAPPL significant		

* Since TIME, AAPPL, and TIME*AAPPL are significant, the behaviour of NO3-N concentrations in the tailings are not consistent over time, i.e. TIME and AAPPL are related.
Refer to the table below for estimates of NO3-N concentrations for different times and application rates.

120 - 150 cm NO3-N (mg/kg):

Level of TIME	Level of AAPPL	N	NO3-N Mean	NO3-N Std. Dev.
_Oct. 1992	_ 62 dt/ha	1	0.1	.
_Oct. 1992	_ 77 dt/ha	2	0.1	0
_Oct. 1992	_179 dt/ha	1	0.1	.
_Apr. 1993	_ 62 dt/ha	1	0.1	.
_Apr. 1993	_ 77 dt/ha	2	0.4	0.071
_Apr. 1993	_179 dt/ha	1	0.3	.
_Sep. 1993	_ 62 dt/ha	1	0.4	.
_Sep. 1993	_ 77 dt/ha	2	0.4	0.071
_Sep. 1993	_179 dt/ha	1	3.0	.

PRINCETON DEMO. PROJECT - NITROGEN & TP - SIG. PARAMETERS

0 - 15 cm NH4-N (mg/kg):

Since TIME, AAPPL, and TIME*AAPPL are significant, the behaviour of NH4-N concentrations in the tailings are not consistent over time, i.e. TIME and AAPPL are related.
Refer to the table below for estimates of NH4-N concentrations for different times and application rates.

Level of TIME	Level of AAPPL	N	NH4-N Mean	NH4-N Std. Dev.
_Oct. 1992	_ 62 dt/ha	1	0.1	.
_Oct. 1992	_ 77 dt/ha	2	1.5	1.6
_Oct. 1992	_179 dt/ha	1	0.2	.
_Apr. 1993	_ 62 dt/ha	1	67	.
_Apr. 1993	_ 77 dt/ha	2	215	14.1
_Apr. 1993	_179 dt/ha	1	347	.
_Sep. 1993	_ 62 dt/ha	1	0.3	.
_Sep. 1993	_ 77 dt/ha	2	1.4	1.3
_Sep. 1993	_179 dt/ha	1	5.2	.

TOTAL P (mg/kg)			
Depth\Time:	**Oct. 1992**	**Apr. 1993**	**Sept. 1993**
0 - 15 cm	1432 b	1628 ab	1868 a
15 - 30 cm *	1437 b	1548 ab	1655 a
30 - 60 cm	average for all times:		1577
60 - 90 cm	average for all times:		1530
90 - 120 cm	average for all times:		1637
120 - 150 cm	average for all times:		1541

* Total P concentration in the 15-30 cm layer is also dependent on the application rate.
Refer to the table below for averages for the different application rates.

15 - 30 cm TOTAL P (mg/kg):

Duncan Group.	Mean	N	AAPPL
a	1685	3	_179 dt/ha
a	1585	6	_ 77 dt/ha
b	1332	3	_ 62 dt/ha

APPENDIX M

Field Experiment - Approximate Nitrogen Balance

PRINCETON DEMONSTRATION PROJECT - APPROXIMATE NITROGEN BALANCE

Assumed dry densities for the nitrogen balance calculations:

Site:	Applicat. Rate: * (dt/ha)	Depth: (cm)	Bulk Density/Site: (kg/m^3)	Weight per 15 cm layer (tonnes/ha)
Control	0	0-15	1340	2010
P2a	77	0-15	1210	1815
P2b	62	0-15	1190	1785
P3a	179	0-15	900	1350
P3b	77	0-15	1120	1680
All Sites		15-150	1340	2010

* Application rate of biosolids in dry tonne/ha
The bulk densities are the average of five measurements per site.

Notes on information contained in the nitrogen balance tables:

All samples were analyzed by the GVRD Lab using laboratory methods described in Appendix O.
The detection limit concentration was used for samples with concentrations below the detection limit.
'% of TKN applied' refers to the ratio of (60-150 cm Mineral N) to TKN-N applied (in percent).
'% of Min. N applied' refers to the ratio of (60-150 cm Mineral N) to Mineral N applied (in percent).

PLOT 2a - NITROGEN BALANCE BASED ON COMPOSITE SOIL SAMPLES

Princeton Tailings - Plot 2a — **Application Rate = 77 dt/ha**

Parameter = Soil TKN — **TKN Applied = 2601 kg/ha**

Depth (cm)	Pre Oct. '92		Post - 1 Apr. '93		Post-1 minus Pre	Post - 2 Sept. '93		Post-2 minus Post-1
	mg/kg	kg/ha	mg/kg	kg/ha	Diff. kg/ha	mg/kg	kg/ha	Diff. kg/ha
0 - 15	56	113	709	1287	1174	1030	1869	583
15 - 30	49	98	147	295	197	212	426	131
30 - 45	74	149	52	105	-44	100	201	96
45 - 60	74	149	52	105	-44	100	201	96
60 - 90	65	261	43	173	-88	80	322	149
90 - 120	57	229	17	68	-161	78	314	245
120 - 150	53	213	48	193	-20	72	289	96
Sum 0-60		509		1791	1283		2698	906

Parameter = Soil Ammonium Nitrogen — **Mineral N Applied = 1288 kg/ha**

Depth (cm)	Pre Oct. '92		Post - 1 Apr. '93		Post-1 minus Pre	Post - 2 Sept. '93		Post-2 minus Post-1
	mg/kg	kg/ha	mg/kg	kg/ha	Diff. kg/ha	mg/kg	kg/ha	Diff. kg/ha
0 - 15	2.6	5.2	204.5	371.2	365.9	0.4	0.7	-370.4
15 - 30	0.1	0.2	77	154.8	154.6	0.2	0.4	-154.4
30 - 45	0.1	0.2	0.9	1.8	1.6	0.3	0.6	-1.2
45 - 60	0.1	0.2	0.9	1.8	1.6	0.3	0.6	-1.2
60 - 90	0.2	0.8	0.3	1.2	0.4	0.1	0.4	-0.8
90 - 120	0.3	1.2	0.1	0.4	-0.8	0.4	1.6	1.2
120 - 150	0.1	0.4	0.1	0.4	0.0	0.7	2.8	2.4
Sum 0-60		6		530	524		2	-527

Parameter = Soil Nitrate Nitrogen — **Mineral N Applied = 1288 kg/ha**

Depth (cm)	Pre Oct. '92		Post - 1 Apr. '93		Post-1 minus Pre	Post - 2 Sept. '93		Post-2 minus Post-1
	mg/kg	kg/ha	mg/kg	kg/ha	Diff. kg/ha	mg/kg	kg/ha	Diff. kg/ha
0 - 15	0.1	0.2	0.2	0.4	0.2	82	148.8	148.5
15 - 30	0.1	0.2	0.3	0.6	0.4	40	80.4	79.8
30 - 45	0.1	0.2	0.3	0.6	0.4	7.3	14.7	14.1
45 - 60	0.1	0.2	0.3	0.6	0.4	7.3	14.7	14.1
60 - 90	0.2	0.8	0.3	1.2	0.4	0.1	0.4	-0.8
90 - 120	0.1	0.4	0.1	0.4	0.0	0.4	1.6	1.2
120 - 150	0.1	0.4	0.4	1.6	1.2	0.4	1.6	0.0
Sum 0-60		**0.8**		**2.2**	**1.4**		**258.6**	**256.4**

	Pre	Post - 1	Post-1 minus Pre	Post - 2	Post-2 minus Post-1
Mineral N:					
0-60 cm Mineral N	**6.6**	**531.7**	**525.1**	**260.9**	**-270.8**
60-150 cm Mineral N	**4.0**	**5.2**	**1.2**	**8.4**	**3.2**
Ratio of (60-150 cm Mineral N) to TKN applied (or Mineral N applied):					
% of TKN Applied	**0.15%**	**0.20%**	**0.05%**	**0.32%**	**0.12%**
% of Min. N Applied	**0.3%**	**0.4%**	**0.1%**	**0.7%**	**0.2%**

PLOT 2a - NITROGEN BALANCE BASED ON DISCRETE SOIL SAMPLES

Princeton Tailings - Plot 2a					Application Rate = 77 dt/ha			
Parameter = Soil TKN					TKN Applied =		2601 kg/ha	
Depth (cm)	Pre Oct. '92		Post - 1 Apr. '93		Post-1 minus Pre	Post - 2 Sept. '93		Post-2 minus Post-1
	mg/kg	kg/ha	mg/kg	kg/ha	Diff. kg/ha	mg/kg	kg/ha	Diff. kg/ha
0 - 15	60	121	213	387	266	817	1483	1096
15 - 30	54	109	48	96	-12	84	169	72
30 - 45	60	121	40	80	-40	56	113	32
45 - 60	51	103	46	92	-10	61	123	30
60 - 90	50	201	80	322	121	53	213	-109
90 - 120								
120 - 150								
Sum 0-60		452		656	204		1887	1231
Parameter = Soil Ammonium Nitrogen					Mineral N Applied =		1288	kg/ha
Depth (cm)	Pre Oct. '92		Post - 1 Apr. '93		Post-1 minus Pre	Post - 2 Sept. '93		Post-2 minus Post-1
	mg/kg	kg/ha	mg/kg	kg/ha	Diff. kg/ha	mg/kg	kg/ha	Diff. kg/ha
0 - 15	0.3	0.6	28.8	52.3	51.7	0.5	0.9	-51.4
15 - 30	0.2	0.4	1.3	2.6	2.2	0.1	0.2	-2.4
30 - 45	0.4	0.8	0.1	0.2	-0.6	0.2	0.4	0.2
45 - 60	0.1	0.2	2.6	5.2	5.0	0.4	0.8	-4.4
60 - 90	0.2	0.8	0.3	1.2	0.4	0.6	2.4	1.2
90 - 120								
120 - 150								
Sum 0-60		2		60	58		2	-58
Parameter = Soil Nitrate Nitrogen					Mineral N Applied =		1288	kg/ha
Depth (cm)	Pre Oct. '92		Post - 1 Apr. '93		Post-1 minus Pre	Post - 2 Sept. '93		Post-2 minus Post-1
	mg/kg	kg/ha	mg/kg	kg/ha	Diff. kg/ha	mg/kg	kg/ha	Diff. kg/ha
0 - 15	0.1	0.2	63.2	114.7	114.5	63.7	115.6	0.9
15 - 30	0.1	0.2	9	18.1	17.9	18.4	37.0	18.9
30 - 45	0.3	0.6	0.5	1.0	0.4	0.9	1.8	0.8
45 - 60	0.1	0.2	0.4	0.8	0.6	0.1	0.2	-0.6
60 - 90	0.1	0.4	1.1	4.4	4.0	0.1	0.4	-4.0
90 - 120								
120 - 150								
Sum 0-60		1.2		134.6	133.4		154.6	20.0
Mineral N:								
0-60 cm Mineral N		3.2		194.9	191.7		156.9	-38.0
60-150 cm Mineral N		1.2		5.6	4.4		2.8	-2.8
Ratio of (60-150 cm Mineral N) to TKN applied (or Mineral N applied):								
% of TKN Applied		0.05%		0.22%	0.17%		0.11%	-0.11%
% of Min. N Applied		0.1%		0.4%	0.3%		0.2%	-0.2%

PLOT 2B - NITROGEN BALANCE BASED ON COMPOSITE SOIL SAMPLES

Princeton Tailings - Plot 2b — **Application Rate = 62 dt/ha**

Parameter = Soil TKN — **TKN Applied = 1616 kg/ha**

Depth (cm)	Pre Oct. '92		Post - 1 Apr. '93		Post-1 minus Pre	Post - 2 Sept. '93		Post-2 minus Post-1
	mg/kg	kg/ha	mg/kg	kg/ha	Diff. kg/ha	mg/kg	kg/ha	Diff. kg/ha
0 - 15	95	191	457	816	625	426	760	-55
15 - 30	75	151	75	151	0	177	356	205
30 - 45	65	131	48	96	-34	94	189	92
45 - 60	65	131	48	96	-34	94	189	92
60 - 90	74	297	58	233	-64	75	302	68
90 - 120	40	161	100	402	241	58	233	-169
120 - 150	54	217	52	209	-8	61	245	36
Sum 0-60		603		1159	556		1494	335

Parameter = Soil Ammonium Nitrogen — **Mineral N Applied = 692 kg/ha**

Depth (cm)	Pre Oct. '92		Post - 1 Apr. '93		Post-1 minus Pre	Post - 2 Sept. '93		Post-2 minus Post-1
	mg/kg	kg/ha	mg/kg	kg/ha	Diff. kg/ha	mg/kg	kg/ha	Diff. kg/ha
0 - 15	0.1	0.2	66.7	119.1	118.9	0.3	0.5	-118.5
15 - 30	0.1	0.2	3.8	7.6	7.4	0.2	0.4	-7.2
30 - 45	0.4	0.8	0.3	0.6	-0.2	0.1	0.2	-0.4
45 - 60	0.4	0.8	0.3	0.6	-0.2	0.1	0.2	-0.4
60 - 90	0.1	0.4	0.3	1.2	0.8	0.1	0.4	-0.8
90 - 120	0.3	1.2	0.3	1.2	0.0	0.1	0.4	-0.8
120 - 150	0.3	1.2	0.3	1.2	0.0	0.1	0.4	-0.8
Sum 0-60		2		128	126		1	-127

Parameter = Soil Nitrate Nitrogen — **Mineral N Applied = 692 kg/ha**

Depth (cm)	Pre Oct. '92		Post - 1 Apr. '93		Post-1 minus Pre	Post - 2 Sept. '93		Post-2 minus Post-1
	mg/kg	kg/ha	mg/kg	kg/ha	Diff. kg/ha	mg/kg	kg/ha	Diff. kg/ha
0 - 15	0.1	0.2	1.9	3.4	3.2	2.8	5.0	1.6
15 - 30	0.1	0.2	0.4	0.8	0.6	7.1	14.3	13.5
30 - 45	0.1	0.2	0.1	0.2	0.0	0.7	1.4	1.2
45 - 60	0.1	0.2	0.1	0.2	0.0	0.7	1.4	1.2
60 - 90	0.1	0.4	0.1	0.4	0.0	0.4	1.6	1.2
90 - 120	0.1	0.4	0.3	1.2	0.8	0.4	1.6	0.4
120 - 150	0.1	0.4	0.1	0.4	0.0	0.4	1.6	1.2
Sum 0-60		**0.8**		**4.6**	**3.8**		**22.1**	**17.5**

Mineral N:

	Pre	Post - 1	Post-1 minus Pre	Post - 2	Post-2 minus Post-1
0-60 cm Mineral N	2.8	132.5	129.7	23.4	-109.1
60-150 cm Mineral N	4.0	5.6	1.6	6.0	0.4

Ratio of (60-150 cm Mineral N) to TKN applied (or Mineral N applied):

	Pre	Post - 1	Post-1 minus Pre	Post - 2	Post-2 minus Post-1
% of TKN Applied	0.25%	0.35%	0.10%	0.37%	0.02%
% of Min. N Applied	0.58%	0.81%	0.23%	0.87%	0.06%

PLOT 2B - NITROGEN BALANCE BASED ON DISCRETE SOIL SAMPLES

Princeton Tailings - Plot 2b — **Application Rate = 62 dt/ha**

Parameter = Soil TKN — **TKN Applied = 1616 kg/ha**

Depth (cm)	Pre Oct. '92		Post - 1 Apr. '93		Post-1 minus Pre	Post - 2 Sept. '93		Post-2 minus Post-1
	mg/kg	kg/ha	mg/kg	kg/ha	Diff. kg/ha	mg/kg	kg/ha	Diff. kg/ha
0 - 15	81	163	278	496	333	339	605	109
15 - 30	77	155	59	119	-36	86	173	54
30 - 45	84	169	74	149	-20	99	199	50
45 - 60	79	159	48	96	-62	91	183	86
60 - 90	92	370	65	261	-109	86	346	84
90 - 120								
120 - 150								
Sum 0-60		645		860	215		1160	300

Parameter = Soil Ammonium Nitrogen — **Mineral N Applied = 692 kg/ha**

Depth (cm)	Pre Oct. '92		Post - 1 Apr. '93		Post-1 minus Pre	Post - 2 Sept. '93		Post-2 minus Post-1
	mg/kg	kg/ha	mg/kg	kg/ha	Diff. kg/ha	mg/kg	kg/ha	Diff. kg/ha
0 - 15	0.3	0.6	16.5	29.5	28.8	0.1	0.2	-29.3
15 - 30	0.1	0.2	0.1	0.2	0.0	0.1	0.2	0.0
30 - 45	0.2	0.4	0.1	0.2	-0.2	0.1	0.2	0.0
45 - 60	0.3	0.6	0.1	0.2	-0.4	0.2	0.4	0.2
60 - 90	0.4	1.6	0.4	1.6	0.0	0.1	0.4	-1.2
90 - 120								
120 - 150								
Sum 0-60		2		30	28		1	-29

Parameter = Soil Nitrate Nitrogen — **Mineral N Applied = 692 kg/ha**

Depth (cm)	Pre Oct. '92		Post - 1 Apr. '93		Post-1 minus Pre	Post - 2 Sept. '93		Post-2 minus Post-1
	mg/kg	kg/ha	mg/kg	kg/ha	Diff. kg/ha	mg/kg	kg/ha	Diff. kg/ha
0 - 15	0.1	0.2	19.5	34.8	34.6	0.5	0.9	-33.9
15 - 30	0.1	0.2	0.1	0.2	0.0	0.1	0.2	0.0
30 - 45	0.2	0.4	0.1	0.2	-0.2	0.2	0.4	0.2
45 - 60	0.1	0.2	0.1	0.2	0.0	0.1	0.2	0.0
60 - 90	0.1	0.4	3.4	13.7	13.3	0.2	0.8	-12.9
90 - 120								
120 - 150								
Sum 0-60		**1.0**		**35.4**	**34.4**		**1.7**	**-33.7**
Mineral N:								
0-60 cm Mineral N		**2.8**		**65.5**	**62.7**		**2.7**	**-62.8**
60-150 cm Mineral N		**2.0**		**15.3**	**13.3**		**1.2**	**-14.1**
Ratio of (60-150 cm Mineral N) to TKN applied (or Mineral N applied):								
% of TKN Applied		**0.12%**		**0.95%**	**0.82%**		**0.07%**	**-0.87%**
% of Min. N Applied		**0.3%**		**2.2%**	**1.9%**		**0.2%**	**-2.0%**

PLOT 3A - NITROGEN BALANCE BASED ON COMPOSITE SOIL SAMPLES

Princeton Tailings - Plot 3a					Application Rate = 179 dt/ha			
Parameter = Soil TKN						TKN Applied =	6048	kg/ha
Depth (cm)	Pre Oct. '92		Post - 1 Apr. '93		Post-1 minus Pre	Post - 2 Sept. '93		Post-2 minus Post-1
	mg/kg	kg/ha	mg/kg	kg/ha	Diff. kg/ha	mg/kg	kg/ha	Diff. kg/ha
0 - 15	34	68	1098	1482	1414	2100	2835	1353
15 - 30	52	105	73	147	42	78	157	10
30 - 45	62	125	33	66	-58	13	26	-40
45 - 60	62	125	33	66	-58	13	26	-40
60 - 90	35	141	33	133	-8	67	269	137
90 - 120	61	245	39	157	-88	59	237	80
120 - 150	56	225	40	161	-64	124	498	338
Sum 0-60		422		1762	1340		3044	1282
Parameter = Soil Ammonium Nitrogen						Mineral N Applied =	2995	kg/ha
Depth (cm)	Pre Oct. '92		Post - 1 Apr. '93		Post-1 minus Pre	Post - 2 Sept. '93		Post-2 minus Post-1
	mg/kg	kg/ha	mg/kg	kg/ha	Diff. kg/ha	mg/kg	kg/ha	Diff. kg/ha
0 - 15	0.2	0.4	346.6	467.9	467.5	5.2	7.0	-460.9
15 - 30	0.3	0.6	19.5	39.2	38.6	0.1	0.2	-39.0
30 - 45	0.3	0.6	1	2.0	1.4	0.3	0.6	-1.4
45 - 60	0.3	0.6	1	2.0	1.4	0.3	0.6	-1.4
60 - 90	0.1	0.4	0.7	2.8	2.4	0.3	1.2	-1.6
90 - 120	0.1	0.4	0.4	1.6	1.2	0.4	1.6	0.0
120 - 150	0.1	0.4	0.1	0.4	0.0	0.4	1.6	1.2
Sum 0-60		2		511	509		8	-503
Parameter = Soil Nitrate Nitrogen						Mineral N Applied =	2995	kg/ha
Depth (cm)	Pre Oct. '92		Post - 1 Apr. '93		Post-1 minus Pre	Post - 2 Sept. '93		Post-2 minus Post-1
	mg/kg	kg/ha	mg/kg	kg/ha	Diff. kg/ha	mg/kg	kg/ha	Diff. kg/ha
0 - 15	0.1	0.2	5.2	7.0	6.8	301	406.4	399.3
15 - 30	0.1	0.2	0.3	0.6	0.4	1.8	3.6	3.0
30 - 45	0.1	0.2	0.1	0.2	0.0	0.3	0.6	0.4
45 - 60	0.1	0.2	0.1	0.2	0.0	0.3	0.6	0.4
60 - 90	0.1	0.4	0.3	1.2	0.8	1	4.0	2.8
90 - 120	0.1	0.4	0.3	1.2	0.8	0.7	2.8	1.6
120 - 150	0.1	0.4	0.3	1.2	0.8	3	12.1	10.9
Sum 0-60		**0.8**		**8.0**	**7.2**		**411.2**	**403.1**
Mineral N:								
0-60 cm Mineral N		**3.0**		**519.2**	**516.1**		**419.6**	**-99.5**
60-150 cm Mineral N		**2.4**		**8.4**	**6.0**		**23.3**	**14.9**
Ratio of (60-150 cm Mineral N) to TKN applied (or Mineral N applied):								
% of TKN Applied		**0.04%**		**0.14%**	**0.10%**		**0.39%**	**0.25%**
% of Min. N Applied		**0.08%**		**0.28%**	**0.20%**		**0.78%**	**0.50%**

PLOT 3A - NITROGEN BALANCE BASED ON DISCRETE SOIL SAMPLES

Princeton Tailings - Plot 3a					Application Rate = 179 dt/ha			
Parameter = Soil TKN				TKN Applied =		6048 kg/ha		
Depth (cm)	Pre Oct. '92		Post - 1 Apr. '93		Post-1 minus Pre	Post - 2 Sept. '93		Post-2 minus Post-1
	mg/kg	kg/ha	mg/kg	kg/ha	Diff. kg/ha	mg/kg	kg/ha	Diff. kg/ha
0 - 15	41.7	84	1108.5	1496	1413	1660	2241	745
15 - 30	49.4	99	32.2	65	-35	98.7	198	134
30 - 45	53.8	108	29.7	60	-48	72.7	146	86
45 - 60	58.6	118	28	56	-62	72	145	88
60 - 90	54.3	218	23.8	96	-123	87	350	254
90 - 120								
120 - 150								
Sum 0-60		409		1677	1268		2730	1053

Parameter = Soil Ammonium Nitrogen					Mineral N Applied =		2995	kg/ha
Depth (cm)	Pre Oct. '92		Post - 1 Apr. '93		Post-1 minus Pre	Post - 2 Sept. '93		Post-2 minus Post-1
	mg/kg	kg/ha	mg/kg	kg/ha	Diff. kg/ha	mg/kg	kg/ha	Diff. kg/ha
0 - 15	0.2	0.4	216.6	292.4	292.0	1.1	1.5	-290.9
15 - 30	0.1	0.2	3.3	6.6	6.4	0.1	0.2	-6.4
30 - 45	0.2	0.4	5.2	10.5	10.1	0.2	0.4	-10.1
45 - 60	0.2	0.4	0.6	1.2	0.8	0.2	0.4	-0.8
60 - 90	0.2	0.8	0.2	0.8	0.0	0.2	0.8	0.0
90 - 120								
120 - 150								
Sum 0-60		1		311	309		2	-308

Parameter = Soil Nitrate Nitrogen					Mineral N Applied =		2995	kg/ha
Depth (cm)	Pre Oct. '92		Post - 1 Apr. '93		Post-1 minus Pre	Post - 2 Sept. '93		Post-2 minus Post-1
	mg/kg	kg/ha	mg/kg	kg/ha	Diff. kg/ha	mg/kg	kg/ha	Diff. kg/ha
0 - 15	0.1	0.2	95.4	128.8	128.6	178.3	240.7	111.9
15 - 30	0.1	0.2	0.2	0.4	0.2	29.7	59.7	59.3
30 - 45	0.1	0.2	4.2	8.4	8.2	9.2	18.5	10.1
45 - 60	0.1	0.2	0.2	0.4	0.2	1.6	3.2	2.8
60 - 90	0.1	0.4	0.2	0.8	0.4	2.6	10.5	9.6
90 - 120								
120 - 150								
Sum 0-60		0.8		138.0	137.2		322.1	184.1
Mineral N:								
0-60 cm Mineral N		2.2		448.7	446.5		324.6	-124.1
60-150 cm Mineral N		1.2		1.6	0.4		11.3	9.6
Ratio of (60-150 cm Mineral N) to TKN applied (or Mineral N applied):								
% of TKN Applied		0.02%		0.03%	0.01%		0.19%	0.16%
% of Min. N Applied		0.04%		0.05%	0.01%		0.38%	0.32%

PLOT 3B - NITROGEN BALANCE BASED ON COMPOSITE SOIL SAMPLES

Princeton Tailings - Plot 3b — **Application Rate = 77 dt/ha**

Parameter = Soil TKN — **TKN Applied = 2601 kg/ha**

Depth (cm)	Pre Oct. '92		Post - 1 Apr. '93		Post-1 minus Pre	Post - 2 Sept. '93		Post-2 minus Post-1
	mg/kg	kg/ha	mg/kg	kg/ha	Diff. kg/ha	mg/kg	kg/ha	Diff. kg/ha
0 - 15	75	151	1180	1982	1832	1460	2453	470
15 - 30	50	101	142	285	185	93	187	-98
30 - 45	60	121	42	84	-36	16	32	-52
45 - 60	60	121	42	84	-36	16	32	-52
60 - 90	55	221	30	121	-101	59	237	117
90 - 120	56	225	45	181	-44	45	181	0
120 - 150	45	181	33	133	-48	41	165	32
Sum 0-60		492		2437	1944		2704	267

Parameter = Soil Ammonium Nitrogen — **Mineral N Applied = 1288 kg/ha**

Depth (cm)	Pre Oct. '92		Post - 1 Apr. '93		Post-1 minus Pre	Post - 2 Sept. '93		Post-2 minus Post-1
	mg/kg	kg/ha	mg/kg	kg/ha	Diff. kg/ha	mg/kg	kg/ha	Diff. kg/ha
0 - 15	0.4	0.8	225	378.0	377.2	2.3	3.9	-374.1
15 - 30	0.1	0.2	14.5	29.1	28.9	0.1	0.2	-28.9
30 - 45	0.1	0.2	0.3	0.6	0.4	0.1	0.2	-0.4
45 - 60	0.1	0.2	0.3	0.6	0.4	0.1	0.2	-0.4
60 - 90	0.1	0.4	0.1	0.4	0.0	0.3	1.2	0.8
90 - 120	0.1	0.4	0.4	1.6	1.2	0.1	0.4	-1.2
120 - 150	0.1	0.4	0.3	1.2	0.8	0.1	0.4	-0.8
Sum 0-60		1		408	407		4	-404

Parameter = Soil Nitrate Nitrogen — **Mineral N Applied = 1288 kg/ha**

Depth (cm)	Pre Oct. '92		Post - 1 Apr. '93		Post-1 minus Pre	Post - 2 Sept. '93		Post-2 minus Post-1
	mg/kg	kg/ha	mg/kg	kg/ha	Diff. kg/ha	mg/kg	kg/ha	Diff. kg/ha
0 - 15	0.3	0.6	14.3	24.0	23.4	157	263.8	239.7
15 - 30	0.1	0.2	0.3	0.6	0.4	87	174.9	174.3
30 - 45	0.1	0.2	0.1	0.2	0.0	3.7	7.4	7.2
45 - 60	0.1	0.2	0.1	0.2	0.0	3.7	7.4	7.2
60 - 90	0.1	0.4	0.3	1.2	0.8	0.4	1.6	0.4
90 - 120	0.1	0.4	0.4	1.6	1.2	0.4	1.6	0.0
120 - 150	0.1	0.4	0.3	1.2	0.8	0.3	1.2	0.0
Sum 0-60		**1.2**		**25.0**	**23.8**		**453.5**	**428.5**

Mineral N:					
0-60 cm Mineral N	**2.6**	**433.4**	**430.8**	**458.0**	**24.6**
60-150 cm Mineral N	**2.4**	**7.2**	**4.8**	**6.4**	**-0.8**
Ratio of (60-150 cm Mineral N) to TKN applied (or Mineral N applied):					
% of TKN Applied	**0.09%**	**0.28%**	**0.19%**	**0.25%**	**-0.03%**
% of Min. N Applied	**0.2%**	**0.6%**	**0.4%**	**0.5%**	**-0.1%**

PLOT 3B - NITROGEN BALANCE BASED ON DISCRETE SOIL SAMPLES

Princeton Tailings - Plot 3b					Application Rate = 77 dt/ha			
Parameter = Soil TKN				TKN Applied =		2601 kg/ha		
Depth (cm)	Pre Oct. '92		Post - 1 Apr. '93		Post-1 minus Pre	Post - 2 Sept. '93		Post-2 minus Post-1
	mg/kg	kg/ha	mg/kg	kg/ha	Diff. kg/ha	mg/kg	kg/ha	Diff. kg/ha
0 - 15	68	137	1336	2244	2108	1295	2176	-69
15 - 30	53	107	31	62	-44	72	145	82
30 - 45	57	115	33	66	-48	86	173	107
45 - 60	60	121	34	68	-52	84	169	101
60 - 90	40	161	23	92	-68	68	273	181
90 - 120								
120 - 150								
Sum 0-60		478		2441	1963		2662	221
Parameter = Soil Ammonium Nitrogen					Mineral N Applied =		1288	kg/ha
Depth (cm)	Pre Oct. '92		Post - 1 Apr. '93		Post-1 minus Pre	Post - 2 Sept. '93		Post-2 minus Post-1
	mg/kg	kg/ha	mg/kg	kg/ha	Diff. kg/ha	mg/kg	kg/ha	Diff. kg/ha
0 - 15	0.2	0.4	286.2	480.8	480.4	0.2	0.3	-480.5
15 - 30	0.3	0.6	0.1	0.2	-0.4	0.1	0.2	0.0
30 - 45	0.1	0.2	0.4	0.8	0.6	0.2	0.4	-0.4
45 - 60	0.1	0.2	0.1	0.2	0.0	0.1	0.2	0.0
60 - 90	0.1	0.4	0.1	0.4	0.0	0.1	0.4	0.0
90 - 120								
120 - 150								
Sum 0-60		1		482	481		1	-481
Parameter = Soil Nitrate Nitrogen					Mineral N Applied =		1288	kg/ha
Depth (cm)	Pre Oct. '92		Post - 1 Apr. '93		Post-1 minus Pre	Post - 2 Sept. '93		Post-2 minus Post-1
	mg/kg	kg/ha	mg/kg	kg/ha	Diff. kg/ha	mg/kg	kg/ha	Diff. kg/ha
0 - 15	0.1	0.2	475.6	799.0	798.8	99.5	167.2	-631.8
15 - 30	0.1	0.2	0.2	0.4	0.2	48	96.5	96.1
30 - 45	0.1	0.2	0.4	0.8	0.6	3.1	6.2	5.4
45 - 60	0.1	0.2	0.1	0.2	0.0	0.4	0.8	0.6
60 - 90	0.1	0.4	0.1	0.4	0.0	0.4	1.6	1.2
90 - 120								
120 - 150								
Sum 0-60		0.8		800.4	799.6		270.7	-529.7
Mineral N:								
0-60 cm Mineral N		2.2		1282.4	1280.2		271.8	-1010.6
60-150 cm Mineral N		0.8		0.8	0.0		2.0	1.2
Ratio of (60-150 cm Mineral N) to TKN applied (or Mineral N applied):								
% of TKN Applied		0.03%		0.03%	0.00%		0.08%	0.05%
% of Min. N Applied		0.06%		0.06%	0.00%		0.16%	0.09%

APPENDIX M

Field Experiment - Nitrogen & Phosphorus Field Data

PRINCETON DEMONSTRATION PROJECT - NITROGEN - FIELD DATA - COMPOSITE AND DISCRETE SAMPLES

TOTAL KJELDAHL NITROGEN - TAILINGS SITES
Concentration of TKN in Soil (mg/kg as N - dry)

				Discrete Sample			Discrete Sample			Discrete Sample		
Site		2a composite			2a - R1			2a - R2			2a - R3	
Appl. Rate (dt/ha)		77			77			77			77	
Depth (cm)	pre	post-1	post-2	pre	post-1	post-2	pre	post-1	post-2	pre	post-1	post-2
	Oct-92	Apr-93	Sep-93	Oct-92	Apr-93	Sep-93	Oct-92	Apr-93	Sep-93	Oct-92	Apr-93	Sep-93
0-15	56	709	1030	50	183	1010	72	108	370	59	348	1070
15-30	49	147	212	78	62	94	61	54	73	22	28	86
30-45	74	52	100	51	41	83	75	42	43	54	36	43
45-60	74	52	100	< 15	44	57	75	44	46	70	51	79
60-90	65	43	80	49	45	33	77	41	74	26	154	51
90-120	57	17	78									
120-150	53	48	72									

TOTAL NO3-N & NO2-N - TAILINGS SITES
Concentration of NO3-N & NO2-N in Soil (mg/kg as N - dry)

				Discrete Sample			Discrete Sample			Discrete Sample		
Site		2a composite			2a - R1			2a - R2			2a - R3	
Depth (cm)	pre	post-1	post-2	pre	post-1	post-2	pre	post-1	post-2	pre	post-1	post-2
	Oct-92	Apr-93	Sep-93	Oct-92	Apr-93	Sep-93	Oct-92	Apr-93	Sep-93	Oct-92	Apr-93	Sep-93
0-15	< 0.1	0.2	82.0	< 0.1	92.8	76.0	0.1	37.3	0.2	< 0.1	59.5	115.0
15-30	< 0.1	0.3	40.0	< 0.1	26.0	52.0	< 0.1	0.6	< 0.1	< 0.1	0.4	3.2
30-45	< 0.1	0.3	7.3	0.9	1.3	2.5	< 0.1	0.1	< 0.1	< 0.1	0.1	< 0.1
45-60	< 0.1	0.3	7.3	< 0.1	0.6	< 0.1	< 0.1	0.4	< 0.1	< 0.2	0.1	< 0.1
60-90	< 0.2	0.3	0.1	< 0.1	2.8	< 0.1	< 0.2	< 0.2	< 0.1	0.2	0.3	< 0.1
90-120	< 0.1	< 0.1	0.4									
120-150	< 0.1	0.4	0.4									

TOTAL AMMONIUM NITROGEN - TAILINGS SITES
Concentration of NH4-N in Soil (mg/kg as N - dry)

				Discrete Sample			Discrete Sample			Discrete Sample		
Site		2a composite			2a - R1			2a - R2			2a - R3	
Depth (cm)	pre	post-1	post-2	pre	post-1	post-2	pre	post-1	post-2	pre	post-1	post-2
	Oct-92	Apr-93	Sep-93	Oct-92	Apr-93	Sep-93	Oct-92	Apr-93	Sep-93	Oct-92	Apr-93	Sep-93
0-15	2.6	204.5	0.4	0.1	0.4	0.4	0.4	0.5	0.2	0.2	85.5	0.8
15-30	0.1	77.0	0.2	0.4	0.4	< 0.1	< 0.1	< 0.1	0.1	0.1	3.4	< 0.1
30-45	< 0.1	0.9	0.3	1.0	0.3	< 1.1	0.1	< 0.1	0.1	< 0.1	< 0.1	< 0.1
45-60	< 0.1	0.9	0.3	< 0.1	< 0.1	< 2.1	< 0.1	< 0.1	0.1	0.3	7.6	< 0.1
60-90	< 0.2	0.3	0.1	< 0.1	0.4	< 3.1	0.5	< 0.2	0.1	0.2	0.3	< 0.1
90-120	0.3	< 0.1	0.4									
120-150	< 0.1	0.1	0.7									

Note:
All samples were analyzed by the GVRD Lab using laboratory methods described in Appendix O.

PRINCETON DEMONSTRATION PROJECT - NITROGEN - FIELD DATA - COMPOSITE AND DISCRETE SAMPLES

TOTAL KJELDAHL NITROGEN - TAILINGS SITES
Concentration of TKN in Soil (mg/kg as N - dry)

				Discrete Sample			Discrete Sample			Discrete Sample		
Site	2b composite			2b - R1			2b - R2			2b - R3		
Appl. Rate (dt/ha)	62			62			62			62		
Depth (cm)	pre	post-1	post-2	pre	post-1	post-2	pre	post-1	post-2	pre	post-1	post-2
	Oct-92	Apr-93	Sep-93	Oct-92	Apr-93	Sep-93	Oct-92	Apr-93	Sep-93	Oct-92	Apr-93	Sep-93
0-15	95	457	426	95	258	270	67	112	330	n/a	465	418
15-30	75	75	177	59	76	69	95	55	97	n/a	47	93
30-45	65	48	94	95	84	110	73	63	89	n/a	74	98
45-60	65	48	94	87	60	101	71	36	88	n/a	49	85
60-90	74	58	75	99	116	79	85	32	88	n/a	45	90
90-120	40	100	58									
120-150	54	52	61									

TOTAL NO3-N & NO2-N - TAILINGS SITES
Concentration of NO3-N & NO2-N in Soil (mg/kg as N - dry)

				Discrete Sample			Discrete Sample			Discrete Sample		
Site	2b composite			2b - R1			2b - R2			2b - R3		
Depth (cm)	pre	post-1	post-2	pre	post-1	post-2	pre	post-1	post-2	pre	post-1	post-2
	Oct-92	Apr-93	Sep-93	Oct-92	Apr-93	Sep-93	Oct-92	Apr-93	Sep-93	Oct-92	Apr-93	Sep-93
0-15	< 0.1	1.9	2.8	< 0.1	26.1	< 0.1	0.1	0.4	0.1	n/a	31.9	1.4
15-30	< 0.1	0.4	7.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.1	n/a	< 0.1	0.1
30-45	0.1	0.1	0.7	0.3	< 0.1	0.3	< 0.1	0.3	< 0.1	n/a	< 0.1	0.1
45-60	0.1	0.1	0.7	< 0.1	< 0.1	0.1	0.1	< 0.1	< 0.1	n/a	< 0.2	< 0.1
60-90	< 0.1	< 0.1	0.4	0.1	10.2	0.3	< 0.1	< 0.1	< 0.1	n/a	< 0.1	0.3
90-120	0.1	0.3	0.4									
120-150	< 0.1	0.1	0.4									

TOTAL AMMONIUM NITROGEN - TAILINGS SITES
Concentration of NH4-N in Soil (mg/kg as N - dry)

				Discrete Sample			Discrete Sample			Discrete Sample		
Site	2b composite			2b - R1			2b - R2			2b - R3		
Depth (cm)	pre	post-1	post-2	pre	post-1	post-2	pre	post-1	post-2	pre	post-1	post-2
	Oct-92	Apr-93	Sep-93	Oct-92	Apr-93	Sep-93	Oct-92	Apr-93	Sep-93	Oct-92	Apr-93	Sep-93
0-15	< 0.1	66.7	0.3	0.1	8.4	< 0.1	0.5	< 0.1	0.2	n/a	41.0	0.1
15-30	0.1	3.8	0.2	0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.1	n/a	< 0.1	0.1
30-45	0.4	0.3	< 0.1	0.3	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	n/a	< 0.1	0.1
45-60	0.4	0.3	< 0.1	< 0.1	< 0.1	0.3	0.6	< 0.1	0.3	n/a	< 0.2	< 0.1
60-90	< 0.1	0.3	< 0.1	0.4	1.2	0.3	0.3	< 0.1	< 0.1	n/a	< 0.1	< 0.1
90-120	0.3	0.3	< 0.1									
120-150	0.3	0.3	< 0.1									

Note:
All samples were analyzed by the GVRD Lab using laboratory methods described in Appendix O.

PRINCETON DEMONSTRATION PROJECT - NITROGEN - FIELD DATA - COMPOSITE AND DISCRETE SAMPLES

TOTAL KJELDAHL NITROGEN - TAILINGS SITES
Concentration of TKN in Soil (mg/kg as N - dry)

				Discrete Sample			Discrete Sample			Discrete Sample		
Site	3a composite			3a - R1			3a - R2			3a - R3		
Appl. Rate (dt/ha)	179											
Depth (cm)	pre	post-1	post-2	pre	post-1	post-2	pre	post-1	post-2	pre	post-1	post-2
	Oct-92	Apr-93	Sep-93	Oct-92	Apr-93	Sep-93	Oct-92	Apr-93	Sep-93	Oct-92	Apr-93	Sep-93
0-15	34	1098	2100	31	1147	2620	60	1479	1340	34	699	1020
15-30	52	73	78	47	46	74	64	23	80	38	28	142
30-45	62	33	< 13	35	23	68	67	43	78	59	23	72
45-60	62	33	< 13	45	28	78	68	27	47	63	29	91
60-90	35	33	67	18	29	68	52	21	81	92	22	112
90-120	61	39	59									
120-150	56	40	124									

TOTAL NO3-N & NO2-N - TAILINGS SITES
Concentration of NO3-N & NO2-N in Soil (mg/kg as N - dry)

				Discrete Sample			Discrete Sample			Discrete Sample		
Site	3a composite			3a - R1			3a - R2			3a - R3		
Depth (cm)	pre	post-1	post-2	pre	post-1	post-2	pre	post-1	post-2	pre	post-1	post-2
	Oct-92	Apr-93	Sep-93	Oct-92	Apr-93	Sep-93	Oct-92	Apr-93	Sep-93	Oct-92	Apr-93	Sep-93
0-15	< 0.1	5.2	301.0	< 0.1	60.1	416.0	< 0.1	163.3	11.0	< 0.1	62.9	108.0
15-30	< 0.1	0.3	1.8	< 0.1	0.3	20.0	< 0.1	< 0.1	45.0	< 0.1	0.3	24.0
30-45	< 0.1	0.1	0.3	< 0.1	0.1	20.0	< 0.1	12.4	7.4	< 0.1	< 0.1	< 0.1
45-60	< 0.1	0.1	0.3	< 0.1	< 0.1	1.0	< 0.1	0.4	3.0	< 0.1	< 0.1	0.8
60-90	< 0.1	0.3	1.0	< 0.2	< 0.2	0.6	< 0.1	0.5	6.0	< 0.2	< 0.1	1.3
90-120	< 0.1	0.3	0.7									
120-150	< 0.1	0.3	3.0									

TOTAL AMMONIUM NITROGEN - TAILINGS SITES
Concentration of NH4-N in Soil (mg/kg as N - dry)

				Discrete Sample			Discrete Sample			Discrete Sample		
Site	3a composite			3a - R1			3a - R2			3a - R3		
Depth (cm)	pre	post-1	post-2	pre	post-1	post-2	pre	post-1	post-2	pre	post-1	post-2
	Oct-92	Apr-93	Sep-93	Oct-92	Apr-93	Sep-93	Oct-92	Apr-93	Sep-93	Oct-92	Apr-93	Sep-93
0-15	0.2	346.6	5.2	< 0.1	226.1	2.4	0.1	209.2	0.3	0.5	214.6	0.7
15-30	0.3	19.5	0.1	< 0.1	0.7	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	9.3	< 0.1
30-45	0.3	1.0	0.3	0.3	0.9	0.1	0.1	13.5	0.3	< 0.1	1.1	< 0.1
45-60	0.3	1.0	0.3	< 0.1	< 0.1	0.1	0.6	1.6	0.3	< 0.1	< 0.1	< 0.1
60-90	< 0.1	0.7	0.3	< 0.2	0.9	< 0.1	0.3	0.6	0.3	< 0.2	1.1	0.3
90-120	< 0.1	0.4	0.4									
120-150	< 0.1	< 0.1	0.4									

Note:
All samples were analyzed by the GVRD Lab using laboratory methods described in Appendix O.

PRINCETON DEMONSTRATION PROJECT - NITROGEN - FIELD DATA - COMPOSITE AND DISCRETE SAMPLES

TOTAL KJELDAHL NITROGEN - TAILINGS SITES
Concentration of TKN in Soil (mg/kg as N - dry)

				Discrete Sample			Discrete Sample			Discrete Sample		
Site	3b composite			3b - R1			3b - R2			3b - R3		
Appl. Rate (dt/ha)	77			77			77			77		
Depth (cm)	pre	post-1	post-2	pre	post-1	post-2	pre	post-1	post-2	pre	post-1	post-2
	Oct-92	Apr-93	Sep-93	Oct-92	Apr-93	Sep-93	Oct-92	Apr-93	Sep-93	Oct-92	Apr-93	Sep-93
0-15	75	1180	1460	64	1273	1480	61	1399	1110	78	n/a	n/a
15-30	50	142	93	50	24	79	51	38	65	57	n/a	n/a
30-45	60	42	16	60	30	95	48	35	77	62	n/a	n/a
45-60	60	42	16	77	42	88	52	26	80	50	n/a	n/a
60-90	55	30	59	43	22	81	44	25	54	34	n/a	n/a
90-120	56	45	45									
120-150	45	33	41									

TOTAL NO3-N & NO2-N - TAILINGS SITES
Concentration of NO3-N & NO2-N in Soil (mg/kg as N - dry)

				Discrete Sample			Discrete Sample			Discrete Sample		
Site	3b composite			3b - R1			3b - R2			3b - R3		
Depth (cm)	pre	post-1	post-2	pre	post-1	post-2	pre	post-1	post-2	pre	post-1	post-2
	Oct-92	Apr-93	Sep-93	Oct-92	Apr-93	Sep-93	Oct-92	Apr-93	Sep-93	Oct-92	Apr-93	Sep-93
0-15	0.3	14.3	157.0	< 0.1	533.8	14.0	< 0.1	417.4	185.0	< 0.1	n/a	n/a
15-30	< 0.1	0.3	87.0	< 0.1	0.3	53.0	< 0.1	< 0.1	43.0	< 0.1	n/a	n/a
30-45	< 0.1	0.1	3.7	< 0.1	0.4	5.0	< 0.1	0.4	1.2	< 0.1	n/a	n/a
45-60	< 0.1	0.1	3.7	0.1	< 0.1	0.5	< 0.1	< 0.1	0.3	< 0.1	n/a	n/a
60-90	< 0.1	0.3	0.4	< 0.1	< 0.1	0.4	< 0.1	< 0.1	0.3	< 0.1	n/a	n/a
90-120	< 0.1	0.4	0.4									
120-150	< 0.1	0.3	0.3									

TOTAL AMMONIUM NITROGEN - TAILINGS SITES
Concentration of NH4-N in Soil (mg/kg as N - dry)

				Discrete Sample			Discrete Sample			Discrete Sample		
Site	3b composite			3b - R1			3b - R2			3b - R3		
Depth (cm)	pre	post-1	post-2	pre	post-1	post-2	pre	post-1	post-2	pre	post-1	post-2
	Oct-92	Apr-93	Sep-93	Oct-92	Apr-93	Sep-93	Oct-92	Apr-93	Sep-93	Oct-92	Apr-93	Sep-93
0-15	0.4	225.0	2.3	< 0.1	35.6	< 0.1	0.3	536.8	0.4	0.2	n/a	n/a
15-30	0.1	14.5	< 0.1	0.3	< 0.1	< 0.1	0.1	< 0.1	< 0.1	0.4	n/a	n/a
30-45	< 0.1	0.3	0.1	< 0.1	0.7	< 0.1	< 0.1	< 0.1	0.4	< 0.1	n/a	n/a
45-60	< 0.1	0.3	0.1	0.1	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1	0.1	n/a	n/a
60-90	< 0.1	< 0.1	0.3	0.1	< 0.1	< 0.1	0.1	< 0.1	< 0.1	0.1	n/a	n/a
90-120	< 0.1	0.4	< 0.1									
120-150	0.1	0.3	0.1									

Note:
All samples were analyzed by the GVRD Lab using laboratory methods described in Appendix O.

PRINCETON DEMONSTRATION PROJECT - PHOSPHORUS - FIELD DATA - COMPOSITE SAMPLES

TOTAL PHOSPHORUS												
Concentration of Total Phosphorus in Soil (mg/kg as P - dry)												
Site	2a composite			2b composite			3a composite			3b composite		
Appl. Rate (dt/ha)	77			62			179			77		
Depth (cm)	pre	post-1	post-2	pre	post-1	post-2	pre	post-1	post-2	pre	post-1	post-2
	Oct-92	Apr-93	Sep-93	Oct-92	Apr-93	Sep-93	Oct-92	Apr-93	Sep-93	Oct-92	Apr-93	Sep-93
0-15	1130	1430	1730	1190	1220	1600	1410	1450	2190	1060	1500	1950
15-30	1270	1120	1660	810	930	1620	1200	1350	1700	1120	1240	1640
30-45	908	1060	1440	1100	1110	1650	921	1370	1900	1160	1100	1680
45-60	908	1060	1440	1100	1110	1650	921	1370	1900	1160	1100	1680
60-90	849	1010	1570	951	1040	1270	1040	1200	1680	1200	1180	1940
90-120	1070	1110	1540	1270	1150	1590	1180	1270	1670	1210	1180	1930
120-150	1050	1090	1440	1110	1020	1640	1180	1230	1620	1200	1410	1400

Notes:
All samples were analyzed by the GVRD Lab using laboratory methods described in Appendix O.
Pre samples were taken prior to biosolids application (early October 1992).
Post-1 samples were taken 6 months after biosolids application (April 1993).
Post-2 samples were taken 12 months after biosolids application (September 1993).
Application rates are reported in dt/ha (dry tonne/hectare).

APPENDIX M

Field Experiment - Nitrogen Averages for Discrete Samples

PRINCETON DEMONSTRATION PROJECT - NITROGEN - AVERAGES FOR DISCRETE SAMPLES

TOTAL KJELDAHL NITROGEN - TAILINGS SITES															
Concentration of TKN in Soil (mg/kg as N - dry)															
				Summary of				Summary of				Summary of			
Site	2a composite			'Discrete 2a' samples				'Discrete 2a' samples				'Discrete 2a' samples			
Appl. Rate (dt/ha)	77			77				77				77			
				Average:	Std. Dev.:	Max.:	Min.:	Average:	Std. Dev.:	Max.:	Min.:	Average:	Std. Dev.:	Max.:	Min.:
Depth (cm)	pre	post-1	post-2	pre	pre	pre	pre	post-1	post-1	post-1	post-1	post-2	post-2	post-2	post-2
	Oct-92	Apr-93	Sep-93	Oct-92	Oct-92	Oct-92	Oct-92	Apr-93	Apr-93	Apr-93	Apr-93	Sep-93	Sep-93	Sep-93	Sep-93
0-15	56	709	1030	60	11	72	50	213	123	348	108	817	388	1070	370
15-30	49	147	212	54	29	78	22	48	18	62	28	84	11	94	73
30-45	74	52	100	60	13	75	51	40	4	42	36	56	23	83	43
45-60	74	52	100	51	37	75	8	46	4	51	44	61	17	79	46
60-90	65	43	80	50	25	77	26	80	64	154	41	53	21	74	33

TOTAL NO3-N - TAILINGS SITES															
Concentration of NO3-N in Soil (mg/kg as N - dry)				Summary of				Summary of				Summary of			
				'Discrete 2a' samples				'Discrete 2a' samples				'Discrete 2a' samples			
Site	2a composite			Average:	Std. Dev.:	Max.:	Min.:	Average:	Std. Dev.:	Max.:	Min.:	Average:	Std. Dev.:	Max.:	Min.:
Depth (cm)	pre	post-1	post-2	pre	pre	pre	pre	post-1	post-1	post-1	post-1	post-2	post-2	post-2	post-2
	Oct-92	Apr-93	Sep-93	Oct-92	Oct-92	Oct-92	Oct-92	Apr-93	Apr-93	Apr-93	Apr-93	Sep-93	Sep-93	Sep-93	Sep-93
0-15	< 0.1	0.2	82.0	0.1	0.0	0.1	0.1	63.2	27.9	92.8	37.3	63.7	58.4	115.0	0.2
15-30	< 0.1	0.3	40.0	0.1	0.0	0.1	0.1	9.0	14.7	26.0	0.4	18.4	29.1	52.0	0.1
30-45	< 0.1	0.3	7.3	0.3	0.5	0.9	0.1	0.5	0.7	1.3	0.1	0.9	1.4	2.5	0.1
45-60	< 0.1	0.3	7.3	0.1	0.0	0.1	0.1	0.4	0.2	0.6	0.1	0.1	0.0	0.1	0.1
60-90	< 0.2	0.3	0.1	0.1	0.1	0.2	0.1	1.1	1.5	2.8	0.1	0.1	0.0	0.1	0.1

TOTAL AMMONIUM NITROGEN - TAILINGS SITES															
Concentration of NH4-N in Soil (mg/kg as N - dry)				Summary of				Summary of				Summary of			
				'Discrete 2a' samples				'Discrete 2a' samples				'Discrete 2a' samples			
Site	2a composite			Average:	Std. Dev.:	Max.:	Min.:	Average:	Std. Dev.:	Max.:	Min.:	Average:	Std. Dev.:	Max.:	Min.:
Depth (cm)	pre	post-1	post-2	pre	pre	pre	pre	post-1	post-1	post-1	post-1	post-2	post-2	post-2	post-2
	Oct-92	Apr-93	Sep-93	Oct-92	Oct-92	Oct-92	Oct-92	Apr-93	Apr-93	Apr-93	Apr-93	Sep-93	Sep-93	Sep-93	Sep-93
0-15	2.6	204.5	0.4	0.3	0.2	0.4	0.1	28.8	49.1	85.5	0.4	0.5	0.3	0.8	0.2
15-30	0.1	77.0	0.2	0.2	0.2	0.4	0.1	1.3	1.8	3.4	0.1	0.1	0.0	0.1	0.1
30-45	< 0.1	0.9	0.3	0.4	0.5	1.0	0.1	0.1	0.1	0.3	0.1	0.2	0.3	0.6	0.1
45-60	< 0.1	0.9	0.3	0.1	0.1	0.3	0.1	2.6	4.4	7.6	0.1	0.4	0.6	1.1	0.1
60-90	< 0.2	0.3	0.1	0.2	0.2	0.5	0.1	0.3	0.2	0.4	0.1	0.6	0.9	1.7	0.1

Samples were analyzed by the GVRD Lab using extraction and digestion methods described in Appendix O.
If the concentration was below the detection limit, half the detection limit concentration was used in the calculations.

PRINCETON DEMONSTRATION PROJECT - NITROGEN - AVERAGES FOR DISCRETE SAMPLES

TOTAL KJELDAHL NITROGEN - TAILINGS SITES															
Concentration of TKN in Soil (mg/kg as N - dry)															
					Summary of				Summary of				Summary of		
Site		2b composite		'Discrete 2b' samples				'Discrete 2b' samples				'Discrete 2b' samples			
Appl. Rate (dt/ha)		62		62				62				62			
				Average:	Std. Dev.:	Max.:	Min.:	Average:	Std. Dev.:	Max.:	Min.:	Average:	Std. Dev.:	Max.:	Min.:
Depth (cm)	pre	post-1	post-2	pre	pre	pre	pre	post-1	post-1	post-1	post-1	post-2	post-2	post-2	post-2
	Oct-92	Apr-93	Sep-93	Oct-92	Oct-92	Oct-92	Oct-92	Apr-93	Apr-93	Apr-93	Apr-93	Sep-93	Sep-93	Sep-93	Sep-93
0-15	95	457	426	81	19	95	67	278	178	465	112	339	74	418	270
15-30	75	75	177	77	25	95	59	59	15	76	47	86	15	97	69
30-45	65	48	94	84	15	95	73	74	11	84	63	99	11	110	89
45-60	65	48	94	79	12	87	71	48	12	60	36	91	9	101	85
60-90	74	58	75	92	10	99	85	65	45	116	32	86	6	90	79

TOTAL NO3-N - TAILINGS SITES															
Concentration of NO3-N in Soil (mg/kg as N - dry)					Summary of				Summary of				Summary of		
				'Discrete 2b' samples				'Discrete 2b' samples				'Discrete 2b' samples			
Site		2b composite		Average:	Std. Dev.:	Max.:	Min.:	Average:	Std. Dev.:	Max.:	Min.:	Average:	Std. Dev.:	Max.:	Min.:
Depth (cm)	pre	post-1	post-2	pre	pre	pre	pre	post-1	post-1	post-1	post-1	post-2	post-2	post-2	post-2
	Oct-92	Apr-93	Sep-93	Oct-92	Oct-92	Oct-92	Oct-92	Apr-93	Apr-93	Apr-93	Apr-93	Sep-93	Sep-93	Sep-93	Sep-93
0-15	< 0.1	1.9	2.8	0.1	0.1	0.1	0.1	19.5	16.8	31.9	0.4	0.5	0.8	1.4	0.1
15-30	< 0.1	0.4	7.1	0.1	0.0	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.0	0.1	0.1
30-45	0.1	0.1	0.7	0.2	0.2	0.3	0.1	0.1	0.0	0.1	0.1	0.2	0.1	0.3	0.1
45-60	0.1	0.1	0.7	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.0	0.1	0.1
60-90	< 0.1	< 0.1	0.4	0.1	0.1	0.1	0.1	3.4	5.9	10.2	0.1	0.2	0.1	0.3	0.1

TOTAL AMMONIUM NITROGEN - TAILINGS SITES															
Concentration of NH4-N in Soil (mg/kg as N - dry)					Summary of				Summary of				Summary of		
				'Discrete 2b' samples				'Discrete 2b' samples				'Discrete 2b' samples			
Site		2b composite		Average:	Std. Dev.:	Max.:	Min.:	Average:	Std. Dev.:	Max.:	Min.:	Average:	Std. Dev.:	Max.:	Min.:
Depth (cm)	pre	post-1	post-2	pre	pre	pre	pre	post-1	post-1	post-1	post-1	post-2	post-2	post-2	post-2
	Oct-92	Apr-93	Sep-93	Oct-92	Oct-92	Oct-92	Oct-92	Apr-93	Apr-93	Apr-93	Apr-93	Sep-93	Sep-93	Sep-93	Sep-93
0-15	< 0.1	66.7	0.3	0.3	0.3	0.5	0.1	16.5	21.7	41.0	0.1	0.1	0.1	0.2	0.1
15-30	0.1	3.8	0.2	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.0	0.1	0.1
30-45	0.4	0.3	< 0.1	0.2	0.2	0.3	0.1	0.1	0.0	0.1	0.1	0.1	0.0	0.1	0.1
45-60	0.4	0.3	< 0.1	0.3	0.4	0.6	0.1	0.1	0.0	0.1	0.1	0.2	0.1	0.3	0.1
60-90	< 0.1	0.3	< 0.1	0.4	0.1	0.4	0.3	0.4	0.7	1.2	0.1	0.1	0.1	0.3	0.1

Samples were analyzed by the GVRD Lab using extraction and digestion methods described in Appendix O.
If the concentration was below the detection limit, half the detection limit concentration was used in the calculations.

PRINCETON DEMONSTRATION PROJECT - NITROGEN - AVERAGES FOR DISCRETE SAMPLES

TOTAL KJELDAHL NITROGEN - TAILINGS SITES															
Concentration of TKN in Soil (mg/kg as N - dry)															
					Summary of				Summary of				Summary of		
Site		3a composite			'Discrete 3a' samples				'Discrete 3a' samples				'Discrete 3a' samples		
Appl. Rate (dt/ha)		179			179				179				179		
				Average:	Std. Dev.:	Max.:	Min.:	Average:	Std. Dev.:	Max.:	Min.:	Average:	Std. Dev.:	Max.:	Min.:
Depth (cm)	pre	post-1	post-2	pre	pre	pre	pre	post-1	post-1	post-1	post-1	post-2	post-2	post-2	post-2
	Oct-92	Apr-93	Sep-93	Oct-92	Oct-92	Oct-92	Oct-92	Apr-93	Apr-93	Apr-93	Apr-93	Sep-93	Sep-93	Sep-93	Sep-93
0-15	34	1098	2100	42	16	60	31	1109	392	1479	699	1660	847	2620	1020
15-30	52	73	78	49	13	64	38	32	12	46	23	99	38	142	74
30-45	62	33	< 13	54	16	67	35	30	12	43	23	73	5	78	68
45-60	62	33	< 13	59	12	68	45	28	1	29	27	72	23	91	47
60-90	35	33	67	54	37	92	18	24	4	29	21	87	23	112	68

TOTAL NO3-N - TAILINGS SITES															
Concentration of NO3-N in Soil (mg/kg as N - dry)					Summary of				Summary of				Summary of		
					'Discrete 3a' samples				'Discrete 3a' samples				'Discrete 3a' samples		
Site		3a composite		Average:	Std. Dev.:	Max.:	Min.:	Average:	Std. Dev.:	Max.:	Min.:	Average:	Std. Dev.:	Max.:	Min.:
Depth (cm)	pre	post-1	post-2	pre	pre	pre	pre	post-1	post-1	post-1	post-1	post-2	post-2	post-2	post-2
	Oct-92	Apr-93	Sep-93	Oct-92	Oct-92	Oct-92	Oct-92	Apr-93	Apr-93	Apr-93	Apr-93	Sep-93	Sep-93	Sep-93	Sep-93
0-15	< 0.1	5.2	301.0	0.1	0.0	0.1	0.1	95.4	58.8	163.3	60.1	178.3	211.5	416.0	11.0
15-30	< 0.1	0.3	1.8	0.1	0.0	0.1	0.1	0.2	0.1	0.3	0.1	29.7	13.4	45.0	20.0
30-45	< 0.1	0.1	0.3	0.1	0.0	0.1	0.1	4.2	7.1	12.4	0.1	9.2	10.1	20.0	0.1
45-60	< 0.1	0.1	0.3	0.1	0.0	0.1	0.1	0.2	0.2	0.4	0.1	1.6	1.2	3.0	0.8
60-90	< 0.1	0.3	1.0	0.1	0.0	0.1	0.1	0.2	0.3	0.5	0.1	2.6	2.9	6.0	0.6

TOTAL AMMONIUM NITROGEN - TAILINGS SITES															
Concentration of NH4-N in Soil (mg/kg as N - dry)					Summary of				Summary of				Summary of		
					'Discrete 3a' samples				'Discrete 3a' samples				'Discrete 3a' samples		
Site		3a composite		Average:	Std. Dev.:	Max.:	Min.:	Average:	Std. Dev.:	Max.:	Min.:	Average:	Std. Dev.:	Max.:	Min.:
Depth (cm)	pre	post-1	post-2	pre	pre	pre	pre	post-1	post-1	post-1	post-1	post-2	post-2	post-2	post-2
	Oct-92	Apr-93	Sep-93	Oct-92	Oct-92	Oct-92	Oct-92	Apr-93	Apr-93	Apr-93	Apr-93	Sep-93	Sep-93	Sep-93	Sep-93
0-15	0.2	346.6	5.2	0.2	0.2	0.5	0.1	216.6	8.7	226.1	209.2	1.1	1.1	2.4	0.3
15-30	0.3	19.5	0.1	0.1	0.0	0.1	0.1	3.3	5.2	9.3	0.1	0.1	0.0	0.1	0.1
30-45	0.3	1.0	0.3	0.2	0.1	0.3	0.1	5.2	7.2	13.5	0.9	0.2	0.1	0.3	0.1
45-60	0.3	1.0	0.3	0.2	0.3	0.6	0.1	0.6	0.9	1.6	0.1	0.2	0.1	0.3	0.1
60-90	< 0.1	0.7	0.3	0.2	0.1	0.3	0.1	0.9	0.2	1.1	0.6	0.2	0.1	0.3	0.1

Samples were analyzed by the GVRD Lab using extraction and digestion methods described in Appendix O.
If the concentration was below the detection limit, half the detection limit concentration was used in the calculations.

PRINCETON DEMONSTRATION PROJECT - NITROGEN - AVERAGES FOR DISCRETE SAMPLES

TOTAL KJELDAHL NITROGEN - TAILINGS SITES															
Concentration of TKN in Soil (mg/kg as N - dry)															
				Summary of				Summary of				Summary of			
Site		3b composite		'Discrete 3b' samples				'Discrete 3b' samples				'Discrete 3b' samples			
Appl. Rate (dt/ha)		77			77				77				77		
				Average:	Std. Dev.:	Max.:	Min.:	Average:	Std. Dev.:	Max.:	Min.:	Average:	Std. Dev.:	Max.:	Min.:
Depth (cm)	pre	post-1	post-2	pre	pre	pre	pre	post-1	post-1	post-1	post-1	post-2	post-2	post-2	post-2
	Oct-92	Apr-93	Sep-93	Oct-92	Oct-92	Oct-92	Oct-92	Apr-93	Apr-93	Apr-93	Apr-93	Sep-93	Sep-93	Sep-93	Sep-93
0-15	75	1180	1460	68	9	78	61	1336	89	1399	1273	1295	262	1480	1110
15-30	50	142	93	53	4	57	50	31	10	38	24	72	10	79	65
30-45	60	42	16	57	7	62	48	33	4	35	30	86	13	95	77
45-60	60	42	16	60	15	77	50	34	11	42	26	84	6	88	80
60-90	55	30	59	40	6	44	34	23	2	25	22	68	19	81	54

TOTAL NO3-N - TAILINGS SITES															
Concentration of NO3-N in Soil (mg/kg as N - dry)				Summary of				Summary of				Summary of			
				'Discrete 3b' samples				'Discrete 3b' samples				'Discrete 3b' samples			
Site		3b composite		Average:	Std. Dev.:	Max.:	Min.:	Average:	Std. Dev.:	Max.:	Min.:	Average:	Std. Dev.:	Max.:	Min.:
Depth (cm)	pre	post-1	post-2	pre	pre	pre	pre	post-1	post-1	post-1	post-1	post-2	post-2	post-2	post-2
	Oct-92	Apr-93	Sep-93	Oct-92	Oct-92	Oct-92	Oct-92	Apr-93	Apr-93	Apr-93	Apr-93	Sep-93	Sep-93	Sep-93	Sep-93
0-15	0.3	14.3	157.0	0.1	0.0	0.1	0.1	475.6	82.3	533.8	417.4	99.5	120.9	185.0	14.0
15-30	< 0.1	0.3	87.0	0.1	0.0	0.1	0.1	0.2	0.2	0.3	0.1	48.0	7.1	53.0	43.0
30-45	< 0.1	0.1	3.7	0.1	0.0	0.1	0.1	0.4	0.0	0.4	0.4	3.1	2.7	5.0	1.2
45-60	< 0.1	0.1	3.7	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.4	0.1	0.5	0.3
60-90	< 0.1	0.3	0.4	0.1	0.0	0.1	0.1	0.1	0.0	0.1	0.1	0.4	0.1	0.4	0.3

TOTAL AMMONIUM NITROGEN - TAILINGS SITES															
Concentration of NH4-N in Soil (mg/kg as N - dry)				Summary of				Summary of				Summary of			
				'Discrete 3b' samples				'Discrete 3b' samples				'Discrete 3b' samples			
Site		3b composite		Average:	Std. Dev.:	Max.:	Min.:	Average:	Std. Dev.:	Max.:	Min.:	Average:	Std. Dev.:	Max.:	Min.:
Depth (cm)	pre	post-1	post-2	pre	pre	pre	pre	post-1	post-1	post-1	post-1	post-2	post-2	post-2	post-2
	Oct-92	Apr-93	Sep-93	Oct-92	Oct-92	Oct-92	Oct-92	Apr-93	Apr-93	Apr-93	Apr-93	Sep-93	Sep-93	Sep-93	Sep-93
0-15	0.4	225.0	2.3	0.2	0.1	0.3	0.1	286.2	354.4	536.8	35.6	0.2	0.2	0.4	0.1
15-30	0.1	14.5	< 0.1	0.3	0.1	0.4	0.1	0.1	0.0	0.1	0.1	0.1	0.0	0.1	0.1
30-45	< 0.1	0.3	0.1	0.1	0.0	0.1	0.1	0.4	0.5	0.7	0.1	0.2	0.2	0.4	0.1
45-60	< 0.1	0.3	0.1	0.1	0.1	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.0	0.1	0.1
60-90	< 0.1	< 0.1	0.3	0.1	0.0	0.1	0.1	0.1	0.0	0.1	0.1	0.1	0.0	0.1	0.1

Samples were analyzed by the GVRD Lab using extraction and digestion methods described in Appendix O.
If the concentration was below the detection limit, half the detection limit concentration was used in the calculations.

APPENDIX M

Field Experiment - Long Form of Nitrogen & Phosphorus Data Analysis

PRINCETON DEMO. PROJECT - NITROGEN & TP - LONG FORM OF DATA ANALYSIS

Class Level Information

Class	Levels	Values		
TIME	3	_Oct. 1992	_Apr. 1993	_Sep. 1993
AAPPL	3	_ 62 dt/ha	_ 77 dt/ha	_179 dt/ha

Number of observations in data set = 12 (DF for Error = 3)

Notes on the Analytical Results:

All samples were analyzed by the GVRD Lab.
The factorial model was used with the parameters AAPPL (application rate) and TIME (time).
R-Square' refers to the R^2 of the model y = TIME|AAPPL in the statistical SAS procedure GLM.
The Duncan multiple range test at the 0.05 level of probability was used to determine significantly different means.
'Std. Dev. ' refers to the sample standard deviation.
'C.V.' refers to the coefficient of variation in percent.
'N' refers to the number of samples for average calculations.
Means preceded by different letters are significantly different.

0 - 15 cm LAYER:

TKN	TIME significant
NH4-N	TIME, AAPPL, AND TIME*AAPPL significant
NO3-N	TIME significant
Total P	TIME significant

0 - 15 cm TKN, mg/kg:

Duncan Grouping	Mean	N	TIME
A	1254	4	_Sep. 1993
A	861	4	_Apr. 1993
B	65	4	_Oct. 1992

0 - 15 cm NH4-N, mg/kg:

Level of TIME	Level of AAPPL	N	NH4-N Mean	NH4-N SD
_Oct. 1992	_ 62 dt/ha	1	0.1	.
_Oct. 1992	_ 77 dt/ha	2	1.5	1.6
_Oct. 1992	_179 dt/ha	1	0.2	.
_Apr. 1993	_ 62 dt/ha	1	67	.
_Apr. 1993	_ 77 dt/ha	2	215	14.1
_Apr. 1993	_179 dt/ha	1	347	.
_Sep. 1993	_ 62 dt/ha	1	0.3	.
_Sep. 1993	_ 77 dt/ha	2	1.4	1.3
_Sep. 1993	_179 dt/ha	1	5.2	.

0 - 15 cm NO3-N, mg/kg:

Duncan Grouping	Mean	N	TIME
A	136	4	_Sep. 1993
B	5.4	4	_Apr. 1993
B	0.2	4	_Oct. 1992

0 - 15 cm Total P, mg/kg:

Duncan Grouping	Mean	N	TIME
A	1868	4	_Sep. 1993
B A	1628	4	_Apr. 1993
B	1432	4	_Oct. 1992

PRINCETON DEMO. PROJECT - NITROGEN & TP - LONG FORM OF DATA ANALYSIS

15 - 30 cm:		R-Square:	C.V.:	Std. Dev.:	Mean:
TKN,	mg/kg	0.781	48	48.6	101.9
NH4-N,	mg/kg	0.639	264	25.5	9.7
NO3-N,	mg/kg	0.856	167	19.2	11.5
Total P		TIME and AAPPL significant			

15-30 cm Total P, mg/kg:

Duncan Grouping		Mean	N	TIME
A		1655	4	_Sep. 1993
B	A	1548	4	_Apr. 1993
B		1437	4	_Oct. 1992

Duncan Grouping	Mean	N	TIME
A	1685	3	_179 dt/ha
A	1585	6	_ 77 dt/ha
B	1332	3	_ 62 dt/ha

30 - 60 cm:		R-Square:	C.V.:	Std. Dev.:	Mean:
TKN,	mg/kg	0.576	64.4	35	54.4
NH4-N,	mg/kg	0.798	73.8	0.3	0.4
NO3-N,	mg/kg	0.879	136	1.5	1.1
Total P,	mg/kg	0.777	11.4	180	1577

60 - 90 cm:		R-Square:	C.V.:	Std. Dev.:	Mean:
TKN,	mg/kg	0.892	19.4	10.9	56.2
NH4-N,	mg/kg	0.827	60.6	0.1	0.2
NO3-N,		TIME significant			
Total P,	mg/kg	0.634	14.2	217	1530

60 - 90 cm NO3-N, mg/kg:

Duncan Grouping		Mean	N	TIME
A		0.5	4	_Sep. 1993
B	A	0.3	4	_Apr. 1993
B		0.1	4	_Oct. 1992

90 - 120 cm:		R-Square:	C.V.:	Std. Dev.:	Mean:
TKN,	mg/kg	0.802	32.4	17.7	54.6
NH4-N,	mg/kg	0.483	84.9	0.2	0.2
NO3-N,		TIME significant			
Total P,	mg/kg	0.339	10.2	167	1637

90 - 120 cm NO3/2-N, mg/kg:

Duncan Grouping		Mean	N	TIME
A		0.5	4	_Sep. 1993
B	A	0.3	4	_Apr. 1993
B		0.1	4	_Oct. 1992

PRINCETON DEMO. PROJECT - NITROGEN & TP - LONG FORM OF DATA ANALYSIS

120-150 cm:		**R-Square:**	**C.V.:**	**Std. Dev.:**	**Mean:**
TKN,	**mg/kg**	0.898	26	14.4	56.6
NH4-N,	**mg/kg**	0.477	115	0.3	0.2
NO3-N		TIME, AAPPL AND TIME*AAPPL significant			
Total P,	**mg/kg**	0.699	8.6	132	1541

120 - 150 cm NO3-N, mg/kg:

Level of	Level of		------------- NO3-N --------------	
TIME	AAPPL	N	Mean	SD
_Oct. 1992	_ 62 dt/ha	1	0.1	.
_Oct. 1992	_ 77 dt/ha	2	0.1	0
_Oct. 1992	_179 dt/ha	1	0.1	.
_Apr. 1993	_ 62 dt/ha	1	0.1	.
_Apr. 1993	_ 77 dt/ha	2	0.4	0.071
_Apr. 1993	_179 dt/ha	1	0.3	.
_Sep. 1993	_ 62 dt/ha	1	0.4	.
_Sep. 1993	_ 77 dt/ha	2	0.4	0.071
_Sep. 1993	_179 dt/ha	1	3.0	.

APPENDIX N

Field Experiment - Total Metals in Soil

PRINCETON DEMONSTRATION PROJECT - METALS - OVERVIEW

Class Level Information

Class	Levels	Values		
TIME	3	_Oct. 1992	_Apr. 1993	_Sep. 1993
AAPPL	2	_77 dt/ha	_179 dt/ha	

Number of observations in data set = 6 (DF for Error = 1)

Metal:		Selenium (mg/kg)	Mercury (mg/kg)	Arsenic (mg/kg)	Aluminum (mg/kg)	Cadmium (mg/kg)	Chromium (mg/kg)
Depth:							
0 - 15 cm	Mean	0.5	TIME	< 5.0	21633	< 0.5	37.8
	Std. Dev.	0.1	sig.		1297		2.2
15 - 30 cm	Mean	0.5	< 0.2	< 5.0	28450	< 0.5	48.7
	Std. Dev.	0.1			1911		3.3
30 - 60 cm	Mean	0.4	< 0.2	TIME	33333	0.5	52.3
	Std. Dev.	0.1		sig.	3747	0.04	1.6
60 - 90 cm	Mean	0.4	< 0.2	3.8	32017	0.6	53.8
	Std. Dev.	0.1		2.7	2763	0.3	4.4
90 - 120 cm	Mean	0.3	< 0.2	TIME	AAPPL	0.5	55.7
	Std. Dev.	0.07		sig.	sig.	0.3	2.2
120 - 150 cm	Mean	0.32	< 0.2	2.9	AAPPL	0.35	54.2
	Std. Dev.	0.04		0.6	sig.	0.04	1.1
Normal Range: *		0.1 - 2	0.02 - 0.2	1 - 50	10000 - 200000	0.01 - 7	5 - 1000
Typical Concentration: *		0.5	0.05	5	50000	0.06	20
CCME: **		2	0.8	20		3	250

Notes:

* Bohn et al., 1985

** lowest of the remediation limits for agricultural or residential soils set by the Canadian Council of Ministers of the Environment (1991)

- Cobalt, nickel, and zinc concentrations remained relatively unchanged.
- Lead concentration was close to the Limit of Detection and tended to be lower after treatment.
- Molybdenum concentration was below the Limit of Detection.

Only the main effects of AAPPL and TIME (i.e. no interactions) were examined in the analysis.
All samples were analyzed by the GVRD Lab.
The Duncan multiple range test at the 0.05 level of probability was used to determine significantly different means.
'Std. Dev. ' refers to the sample standard deviation.

PRINCETON DEMONSTRATION PROJECT - METALS - SIGNIF. PARAMETERS

0 - 15 cm Mercury (mg/kg):

Duncan Grouping	Mean	N	TIME
A	0.4	2	_Sep. 1993
B	0.1	2	_Oct. 1992
B	0.1	2	_Apr. 1993

30 - 60 cm Arsenic (mg/kg):

Duncan Grouping	Mean	N	TIME
A	5.0	2	_Apr. 1993
B	3.0	2	_Oct. 1992
B	2.5	2	_Sep. 1993

90 - 120 cm Arsenic (As), mg/kg:

Duncan Grouping	Mean	N	TIME
A	5.0	2	_Apr. 1993
B	3.0	2	_Oct. 1992
C	2.5	2	_Sep. 1993

90 - 120 cm Aluminum (mg/kg):

Duncan Grouping	Mean	N	AAPPL
A	33500	3	_ 77 dt/ha
B	26767	3	_179 dt/ha

120 - 150 cm Aluminum (mg/kg):

Duncan Grouping	Mean	N	AAPPL
A	30333	3	_ 77 dt/ha
B	24433	3	_179 dt/ha

PRINCETON DEMONSTRATION PROJECT - TOTAL METALS - FIELD DATA - COMPOSITE SAMPLES

TOTAL ARSENIC- TAILINGS SITES
Concentration of Arsenic in Soil (mg/kg)

Site	2a			3a		
Depth (cm)	pre	post-1	post-2	pre	post-1	post-2
	Oct-92	Apr-93	Sep-93	Oct-92	Apr-93	Sep-93
0-15	< 5	< 5	< 5	< 5	< 5	< 5
15-30	< 5	< 5	< 5	< 5	< 5	< 5
30-60	< 7	5	< 5	< 5	5	< 5
60-90	< 6	9	< 5	< 6	< 5	< 5
90-120	< 6	5	< 5	< 6	5	< 5
120-150	< 6	4	< 5	< 6	< 5	< 5

Limit of Detection (LOD) = 7 mg/kg (most conservative LOD)
Limit of Quantitation (LOQ) = 21 mg/kg (plus or minus 30% accuracy)

TOTAL CADMIUM - TAILINGS SITES
Concentration of Cadmium in Soil (mg/kg)

Site	2a			3a		
Depth (cm)	pre	post-1	post-2	pre	post-1	post-2
	Oct-92	Apr-93	Sep-93	Oct-92	Apr-93	Sep-93
0-15	< 0.5	0.5	0.5	< 0.5	0.5	0.5
15-30	0.5	0.4	0.5	0.5	0.4	0.5
30-60	< 0.7	0.5	0.5	< 0.6	0.5	0.5
60-90	< 0.6	0.9	< 0.5	< 0.6	0.8	0.9
90-120	< 0.6	0.9	< 0.5	< 0.6	0.4	0.5
120-150	< 0.6	0.4	< 0.5	< 0.6	0.5	< 0.5

Limit of Detection (LOD) = 0.7 mg/kg (most conservative LOD)
Limit of Quantitation (LOQ) = 2.1 mg/kg (plus or minus 30% accuracy)

TOTAL CHROMIUM - TAILINGS SITES
Concentration of Chromium in Soil (mg/kg)

Site	2a			3a		
Depth (cm)	pre	post-1	post-2	pre	post-1	post-2
	Oct-92	Apr-93	Sep-93	Oct-92	Apr-93	Sep-93
0-15	41	30	42	42	33	39
15-30	43	43	46	56	54	50
30-60	49	52	52	53	52	56
60-90	53	52	58	59	49	52
90-120	58	58	56	52	54	56
120-150	56	55	55	52	53	54

Limit of Detection (LOD) = 2 mg/kg (most conservative LOD)
Limit of Quantitation (LOQ) = 6 mg/kg (plus or minus 30% accuracy)

TOTAL COBALT - TAILINGS SITES
Concentration of Cobalt in Soil (mg/kg)

Site	2a			3a		
Depth (cm)	pre	post-1	post-2	pre	post-1	post-2
	Oct-92	Apr-93	Sep-93	Oct-92	Apr-93	Sep-93
0-15	19	14	19	18	14	17
15-30	22	20	19	22	19	21
30-60	26	22	25	21	23	23
60-90	26	24	22	26	21	22
90-120	23	24	23	22	20	20
120-150	23	19	22	20	19	19

Limit of Detection (LOD) = 4 mg/kg (most conservative LOD)
Limit of Quantitation (LOQ) = 12 mg/kg (plus or minus 30% accuracy)

PRINCETON DEMONSTRATION PROJECT - TOTAL METALS - FIELD DATA - COMPOSITE SAMPLES

TOTAL COPPER - TAILINGS SITES						
Concentration of Copper in Soil (mg/kg)						
Site	**2a**			**3a**		
Depth (cm)	**pre**	**post-1**	**post-2**	**pre**	**post-1**	**post-2**
	Oct-92	**Apr-93**	**Sep-93**	**Oct-92**	**Apr-93**	**Sep-93**
0-15	1720	1200	1450	1250	1260	1240
15-30	1590	2130	1370	2270	1870	1570
30-60	2000	2060	2020	1420	1760	1300
60-90	1930	2670	1740	1580	1520	1590
90-120	1480	1800	1870	1370	1290	1440
120-150	1420	1610	1540	1280	1290	1370

Limit of Detection (LOD) = 4 mg/kg (most conservative LOD)
Limit of Quantitation (LOQ) = 12 mg/kg (plus or minus 30% accuracy)

TOTAL LEAD - TAILINGS SITES						
Concentration of Lead in Soil (mg/kg)						
Site	**2a**			**3a**		
Depth (cm)	**pre**	**post-1**	**post-2**	**pre**	**post-1**	**post-2**
	Oct-92	**Apr-93**	**Sep-93**	**Oct-92**	**Apr-93**	**Sep-93**
0-15	19	8	13	13	8	19
15-30	17	6	6	23	6	7
30-60	22	7	4	11	5	< 5
60-90	20	6	10	15	< 3	8
90-120	18	3	4	13	4	6
120-150	14	< 3	6	12	< 3	6

Limit of Detection (LOD) = 5 mg/kg (most conservative LOD)
Limit of Quantitation (LOQ) = 15 mg/kg (plus or minus 30% accuracy)

TOTAL MERCURY - TAILINGS SITES						
Concentration of Mercury in Soil (mg/kg)						
Site	**2a**			**3a**		
Depth (cm)	**pre**	**post-1**	**post-2**	**pre**	**post-1**	**post-2**
	Oct-92	**Apr-93**	**Sep-93**	**Oct-92**	**Apr-93**	**Sep-93**
0-15	< 0.2	0.1	0.3	< 0.2	0.2	0.4
15-30	< 0.2	< 0.1	< 0.1	< 0.2	< 0.1	< 0.1
30-60	< 0.2	< 0.1	< 0.1	< 0.1	< 0.1	< 0.1
60-90	< 0.2	< 0.1	< 0.1	< 0.2	< 0.1	< 0.1
90-120	< 0.2	< 0.1	< 0.1	< 0.2	< 0.1	< 0.1
120-150	< 0.2	< 0.1	< 0.1	< 0.2	< 0.1	< 0.1

Limit of Detection (LOD) = 0.2 mg/kg (most conservative LOD)
Limit of Quantitation (LOQ) = 0.6 mg/kg (plus or minus 30% accuracy)

TOTAL MOLYBDENUM - TAILINGS SITES						
Concentration of Molybdenum in Soil (mg/kg)						
Site	**2a**			**3a**		
Depth (cm)	**pre**	**post-1**	**post-2**	**pre**	**post-1**	**post-2**
	Oct-92	**Apr-93**	**Sep-93**	**Oct-92**	**Apr-93**	**Sep-93**
0-15	< 2	< 1.4	< 1.5	< 2	< 1.4	< 1.5
15-30	< 2	< 1.3	< 1.5	< 2	< 1.3	< 1.5
30-60	< 2	< 1.4	< 1.5	< 2	< 1.4	< 1.5
60-90	< 2	< 1.4	< 1.5	< 2	< 1.2	< 1.5
90-120	< 2	< 1.4	< 1.5	< 2	1.3	< 1.5
120-150	< 2	< 1.2	< 1.5	< 2	< 1.4	< 1.5

Limit of Detection (LOD) = 2 mg/kg (most conservative LOD)
Limit of Quantitation (LOQ) = 6 mg/kg (plus or minus 30% accuracy)

PRINCETON DEMONSTRATION PROJECT - TOTAL METALS - FIELD DATA - COMPOSITE SAMPLES

TOTAL NICKEL - TAILINGS SITES						
Concentration of Nickel in Soil (mg/kg)						
Site	2a			3a		
Depth (cm)	pre	post-1	post-2	pre	post-1	post-2
	Oct-92	Apr-93	Sep-93	Oct-92	Apr-93	Sep-93
0-15	24	14	19	24	15	21
15-30	27	24	21	30	24	26
30-60	28	32	28	26	27	27
60-90	29	27	28	29	22	25
90-120	29	28	27	26	23	24
120-150	29	31	26	28	23	25

Limit of Detection (LOD) = 4 mg/kg (most conservative LOD)
Limit of Quantitation (LOQ) = 12 mg/kg (plus or minus 30% accuracy)

TOTAL SELENIUM - TAILINGS SITES						
Concentration of Selenium in Soil (mg/kg)						
Site	2a			3a		
Depth (cm)	pre	post-1	post-2	pre	post-1	post-2
	Oct-92	Apr-93	Sep-93	Oct-92	Apr-93	Sep-93
0-15	0.5	0.4	0.5	0.3	0.5	0.5
15-30	0.5	0.7	0.3	0.6	0.6	0.3
30-60	0.6	0.3	0.6	0.5	0.3	0.6
60-90	0.5	0.3	0.5	0.4	0.3	0.5
90-120	0.4	0.3	0.3	0.4	0.3	0.3
120-150	0.4	0.3	0.3	0.3	0.3	0.3

Limit of Detection (LOD) = 0.1 mg/kg (most conservative LOD)
Limit of Quantitation (LOQ) = 0.3 mg/kg (plus or minus 30% accuracy)

TOTAL ZINC - TAILINGS SITES						
Concentration of Zinc in Soil (mg/kg)						
Site	2a			3a		
Depth (cm)	pre	post-1	post-2	pre	post-1	post-2
	Oct-92	Apr-93	Sep-93	Oct-92	Apr-93	Sep-93
0-15	88	69	98	82	82	124
15-30	101	97	80	106	86	86
30-60	111	99	106	96	104	93
60-90	117	109	101	105	84	87
90-120	96	108	103	82	86	73
120-150	91	96	93	80	75	72

Limit of Detection (LOD) = 2 mg/kg (most conservative LOD)
Limit of Quantitation (LOQ) = 6 mg/kg (plus or minus 30% accuracy)

PRINCETON DEMO. PROJECT - METALS - LONG FORM OF ANALYSIS

Class Level Information

Class	Levels	Values		
TIME	3	_Oct. 1992	_Apr. 1993	_Sep. 1993
AAPPL	2	_ 77 dt/ha	_179 dt/ha	

Number of observations in data set = 6 (DF for Error = 1)

Notes:
Only the main effects of AAPPL and TIME (i.e. no interactions) were examined in the data analysis.
All samples were analyzed by the GVRD Lab.
R-Square' refers to the R^2 of the model 'y = TIME AAPPL' in the statistical SAS procedure GLM.
The Duncan multiple range test at the 0.05 level of probability was used to determine significantly different means.
'Std. Dev. ' refers to the sample standard deviation.
'C.V.' refers to the coefficient of variation in percent.
'N' refers to the number of samples for average calculations.
Means preceded by different letters are significantly different.

		R-Square:	**C.V.:**	**Std. Dev.:**	**Mean:**
0 - 15 cm LAYER:					
Selenium,	**mg/kg**	0.438	26.2	0.1	0.5
Mercury		TIME significant			
Arsenic,	**mg/kg**	all values			< 5.0
Aluminum,	**mg/kg**	0.949	6	1297	21633
Cadmium,	**mg/kg**	all values			< 0.5
Chromium,	**mg/kg**	0.929	5.7	2.2	37.8
15 - 30 cm LAYER:					
Selenium,	**mg/kg**	0.929	14.1	0.1	0.5
Mercury,	**mg/kg**	all values			< 0.2
Arsenic,	**mg/kg**	all values			< 5.0
Aluminum,	**mg/kg**	0.727	6.7	1911	28450
Cadmium,	**mg/kg**	all values			< 0.5
Chromium,	**mg/kg**	0.856	6.9	3.3	48.7
30 - 60 cm LAYER:					
Selenium,	**mg/kg**	0.794	24.9	0.1	0.4
Mercury,	**mg/kg**	all values			< 0.2
Arsenic		TIME significant			
Aluminum,	**mg/kg**	0.457	11.2	3747	33333
Cadmium,	**mg/kg**	0.905	9.1	0.04	0.5
Chromium,	**mg/kg**	0.789	3.1	1.6	52.3
60 - 90 cm LAYER:					
Selenium,	**mg/kg**	0.793	18.4	0.1	0.4
Mercury,	**mg/kg**	all values			< 0.2
Arsenic,	**mg/kg**	0.578	70.8	2.7	3.8
Aluminum,	**mg/kg**	0.849	8.6	2763	32017
Cadmium,	**mg/kg**	0.706	45.9	0.3	0.6
Chromium,	**mg/kg**	0.479	8.2	4.4	53.8

PRINCETON DEMO. PROJECT - METALS - LONG FORM OF ANALYSIS

		R-Square:	C.V.:	Std. Dev.:	Mean:
90 - 120 cm LAYER:					
Selenium,	**mg/kg**	0.882	12.9	0.07	0.3
Mercury,	**mg/kg**	all values			< 0.2
Arsenic		TIME significant			
Aluminum		AAPPL significant			
Cadmium,	**mg/kg**	0.527	56.7	0.3	0.5
Chromium,	**mg/kg**	0.659	3.9	2.2	55.7
120 - 150 cm LAYER:					
Selenium,	**mg/kg**	0.6	12.9	0.04	0.32
Mercury,	**mg/kg**	all values			< 0.2
Arsenic,	**mg/kg**	0.561	21	0.61	2.9
Aluminum		AAPPL significant			
Cadmium,	**mg/kg**	0.905	11.7	0.04	0.35
Chromium,	**mg/kg**	0.785	2	1.08	54.2

0 - 15 cm Mercury (Hg), mg/kg:

Duncan Grouping	Mean	N	TIME
A	0.35	2	_Sep. 1993
B	0.1	2	_Oct. 1992
B	0.1	2	_Apr. 1993

30 - 60 cm Arsenic (As), mg/kg:

Duncan Grouping	Mean	N	TIME
A	5	2	_Apr. 1993
B	3	2	_Oct. 1992
B	2.5	2	_Sep. 1993

90 - 120 cm Arsenic (As), mg/kg:

Duncan Grouping	Mean	N	TIME
A	5	2	_Apr. 1993
B	3	2	_Oct. 1992
C	2.5	2	_Sep. 1993

90 - 120 cm Aluminum (Al), mg/kg:

Duncan Grouping	Mean	N	AAPPL
A	33500	3	_ 77 dt/ha
B	26767	3	_179 dt/ha

120 - 150 cm Aluminum (Al), mg/kg:

Duncan Grouping	Mean	N	AAPPL
A	30333	3	_ 77 dt/ha
B	24433	3	_179 dt/ha

APPENDIX O

Laboratory Methods

Laboratory Methods used in the Princeton Demonstration Project and the Leaching Experiments:

Parameter:

pH:

BIOE: pH of filtrate of a 1:2 w/v soil:DI slurry is measured with a pH meter. The result is reported as 1:2 pH.

NORW: pH of a 1:2 v/v soil:water slurry is determined with a pH meter (MSS 4.13).

Electrical Conductivity:

BIOE: EC of filtrate of a 1:2 w/v slurry is measured using an EC meter. The result is reported as 1:2 EC (MSA 10-2).

NORW: EC is measured on water phase of a 1:2 v/v DI extraction using an EC meter. The measured EC value is converted to a saturated extract equivalent EC by multiplying by 2 (MSS 4.13).

Total Kjeldahl Nitrogen:

BIOE: Percolate Water Analysis:

Digestion of 10 mL percolate water with 5 mL H_2SO_4 and potassium sulfate/copper sulfate/ selenium dioxide mixture followed by the Technicon salicylate/hypochlorite colorimetric determination (660 nm).

Soil Analysis:

Digestion of 2-2.5 g sample with 5-10 mL H_2SO_4 and potassium sulfate/copper sulfate/selenium dioxide mixture. Same colorimetric determination as above.

GVRD: Soil Analysis:

Digestion of 2.5 g sample with 50 mL Mercuric sulfate ($HgO + H_2SO_4$ + DI) and potassium sulfate ($K_2SO_4 + H_2SO_4$ + DI) solution in 800 mL Kjeldahl flask. Colorimetric determination with salicylate/hypochlorite method (APHA (1989); LMM 10-107-06-2-F).

NORW: Plant Tissue Analysis:

Digestion with H_2SO_4 and potassium sulfate/ copper sulfate/selenium mixture. Determination of NH_4^+ by steam distillation and titration. The result is reported as %N.

Ammonium:

BIOE: Percolate Water Analysis:

NH_4^+ is measured using the sodium phenolate/sodium hypochlorite/potassium sodium tartrate colour method (Technicon AAII 98-70W; 630 nm).

Soil Analysis:

Extraction (1:10 w/v) with 2 M potassium chloride. Same determination method as above.

GVRD: Soil Analysis:

Extraction (1:10 w/v) with 2 M potassium chloride. NH_4^+ is measured with the Lachat sodium phenolate/sodium hypochlorite method (LMM 10-107-06-1-B; MSA 33-7).

NORW: Soil Analysis:

Extraction (1:10 w/v) with 1 M potassium chloride. NH_4^+ is measured with the Technicon sodium phenolate/hypochlorite/potassium sodium tartrate colorimetric method.

Note:
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GVRD Greater Vancouver Regional District Laboratory, Burnaby, B.C.
NORW Norwest Soil Research Inc. Laboratory, Langley, B.C.

Nitrate:

BIOE: Percolate Water Analysis:

NO_3^- is determined by cadmium reduction and colour reaction with sulfanilamide and 1-naphthylethylenediamine dihydrochloride (Technicon AAII 100-70W; 520 nm).

Soil Analysis:

Extraction (1:10 w/v) with 2 M potassium chloride. Same colorimetric determination method as above.

GVRD: Soil Analysis:

Extraction (1:10 w/v) with 2 M potassium chloride. NO_3^- is determined by cadmium reduction and colour reaction with sulfanilamide and 1-naphthylethylenediamine dihydrochloride (520 nm) (LMM 10-107-04-1-B; MSA 33-8).

NORW: Soil Analysis:

Extraction (1:10 w/v) with 1 M potassium chloride. NO_3^- is determined by cadmium reduction and colour reaction with sulphanilamide and naphthylethylenediamine (APHA 4500).

Plant Tissue Analysis:

Extraction (1:20 w/v) with 1 M potassium chloride. NO_3^- is determined by cadmium reduction and colour reaction with sulphanilamide and naphthylethylenediamine. The result is reported in %NO_3-N.

Available Phosphorus:

BIOE: Extraction (1:20 w/v) with 0.5 M $NaHCO_3$ at pH 8.5 (Olsen-P extr.). Manual determination of P with ammonium paramolybdate/antimony potassium tartrate/ascorbic acid method (MSA 24-5).

NORW: Extraction (1:10 w/v) with 0.03 N ammonium fluoride/0.025 N hydrochloric acid (Bray-P1 extr.). P is measured using the Technicon ammonium molybdate/antimony potassium tartrate/ascorbic acid method SSW 26:178).

Total Phosphorus:

BIOE: Percolate Water Analysis:

Digestion of 10 mL sample with 1 mL H_2SO_4 and 5 mL HNO_3. Determination of TP by Stannous Chloride Method (690 nm) (APHA (1989) 424C & E).

GVRD: Soil Analysis:

Digestion of 2.5 g sample with 25 mL HNO_3 and 10 mL H_2SO_4. Determination of TP by Stannous Chloride method.

NORW: Plant Tissue Analysis:

Nitric/perchloric acid digestion. Determination of TP by Technicon ammoniun molydate/antimony potassium tartrate/ascorbic acid method.

Ca^{2+}, Mg^{2+}, K^+, Na^+:

NORW: Soil Analysis (exchangeable cations):

Extraction (1:5 w/v) with 1 M neutral ammonium acetate. Exchangeable cations are determined by Atomic Absorption spectrophotometry (A.A.S.) (MSA 9-3).

Boron:

NORW: Available B in soil:

Hot water extraction (1:4 w/v). Determination of B with Technicon azomethine-H method (MSA 25-5 & 25-9).

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Sulfate:

NORW: Extraction (1:2 w/v) with 0.01 M Calcium chloride. SO_4^{2-} is measured turbidimetrically.

Sulfur:

NORW: Nitric/perchloric acid digestion. Turbidimetrical determination of S with Barium chloride.

Zinc, Iron, Copper, Manganese:

NORW: Available nutrients in soil:
Extraction (1:2 w/v) with DTPA-TEA solution. Individual cations are determined by A.A.S. (MSS 4.65; EPA 6010).
Plant Tissue Analysis (Total cations):
Nitric/perchloric acid digestion. Determination of Cu and Zn by A.A.S.

Total As, Cd, Cr, Cu, Pb, Mo, Ni, and Zn:

GVRD: Soil Analysis:
Aqua regia digestion followed by an Inductively Coupled Plasma Spectrometer (ICP) analysis.

NORW: Plant Tissue Analysis:
Nitric/perchloric acid digestion followed by an ICP analysis for As, Cd, Cr, Pb, Mo, and Ni.

Total Al, Co:

GVRD: Aqua regia digestion followed by an ICP analysis.

Total Se:

GVRD: Soil Analysis:
Nitric/perchloric acid digestion. Reduction of inorganic Se with hydrochloric acid at 90°C. Hydrides generation with sodium borohydride. Determination of Se by hydride A.A.S. LMCA; APHA (1989)).

NORW: Plant Tissue Analysis:
Nitric/perchloric acid digestion. Determination of Se by hydride A.A.S. (APHA 3114B).

Total Hg:

GVRD: Soil Analysis:
Aqua regia digestion (inorg. Hg) followed by sulfuric acid/potassium permanganate/potassium persulphate digestion (org. Hg). Reduction of permanganate followed by reduction of mercury with Stannous chloride followed by cold vapor A.A.S. (AMM; LMCA; EPA 7471).

NORW: Plant Tissue Analysis:
Nitric/perchloric acid digestion followed by cold vapor A.A.S.

Loss on Ignition:

BIOE: Ignition of 40-60 g sample for 3 hours at 450°C. The lost weight includes organic matter, water of crystallization, and volatiles.

Organic Matter:

NORW: Determination of Total Carbon with an induction furnace and an infrared detector. Estimation of organic matter by multiplying carbon content by 1.78.

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Particle Size Distribution:

NORW and BIOE:

Hydrometer Method (MSA 15-5).

Particle Density:

BIOE: Pycnometer Method (MSA 14-3).

Pretreatment of Samples:

Soil Samples:

BIOE: Manual homogenization of samples. All constituents of the soil samples analyzed were below 2 mm in size. Samples were analyzed on a wet basis for TKN, ammonium, and nitrate and on an air-dried basis for the determination of Olsen-P, pH and EC.

GVRD: A flow chart of the sample pretreatment at the GVRD Lab follows on the next page.

NORW: Norwest analyzed the below 2 mm fraction of soil samples on a ovendry basis for all parameters.

Vegetation Samples:

NORW: All plant tissue samples were dried at 60 °C and ground. The below 1 mm fraction of the ground samples was used for further analysis.

References for Laboratory Methods:

APHA Amercian Public Health Association. 1992. Standard Methods for the Examination of Water and Wastewater. 18th ed.

ASSW Alberta Soil Science Workshop Proceedings.

EPA EPA. 1986. Test Methods for Evaluating Solid Waste. Physical/Chemical Methods. SW-846, 3rd ed. U.S. EPA, Off. of Sol. Waste and Emergency Response.

MSS McKeague, J.A. . Manual on Soil Sampling and Methods of Analysis. 2nd ed. CSSS.

MSA Page, A.L., R.H. Miller, and D.R. Keeney (eds.). 1982. Methods of Soil Analysis. Am. Soc. Agron, Soil Sc. Soc. of Am. Madison, Wisconsin, U.S.A.

AMM B.C. MOE. 1978. Mercury in Sediments (Cold Vapour Atomic Absorption). *In* Analytical Methods Manual 1979 & Updates. Inland Waters Directorate. Water Quality Branch.

LMCA B.C. MOE. 1976. A Laboratory Manual for the Chemical Analysis of Waters, Wastewaters, Sediments, and Biological Materials. Data Standards Group, Waste Management Branch.

LMM Lachat Methods Manual. Determination of NH_3 and NO_3 in Soil.

Note:

BIOE Bio-Resource Engineering Laboratory, U.B.C., Vancouver, B.C.

GVRD Greater Vancouver Regional District Laboratory,Burnaby, B.C.

NORW Norwest Soil Research Inc. Laboratory, Langley, B.C.

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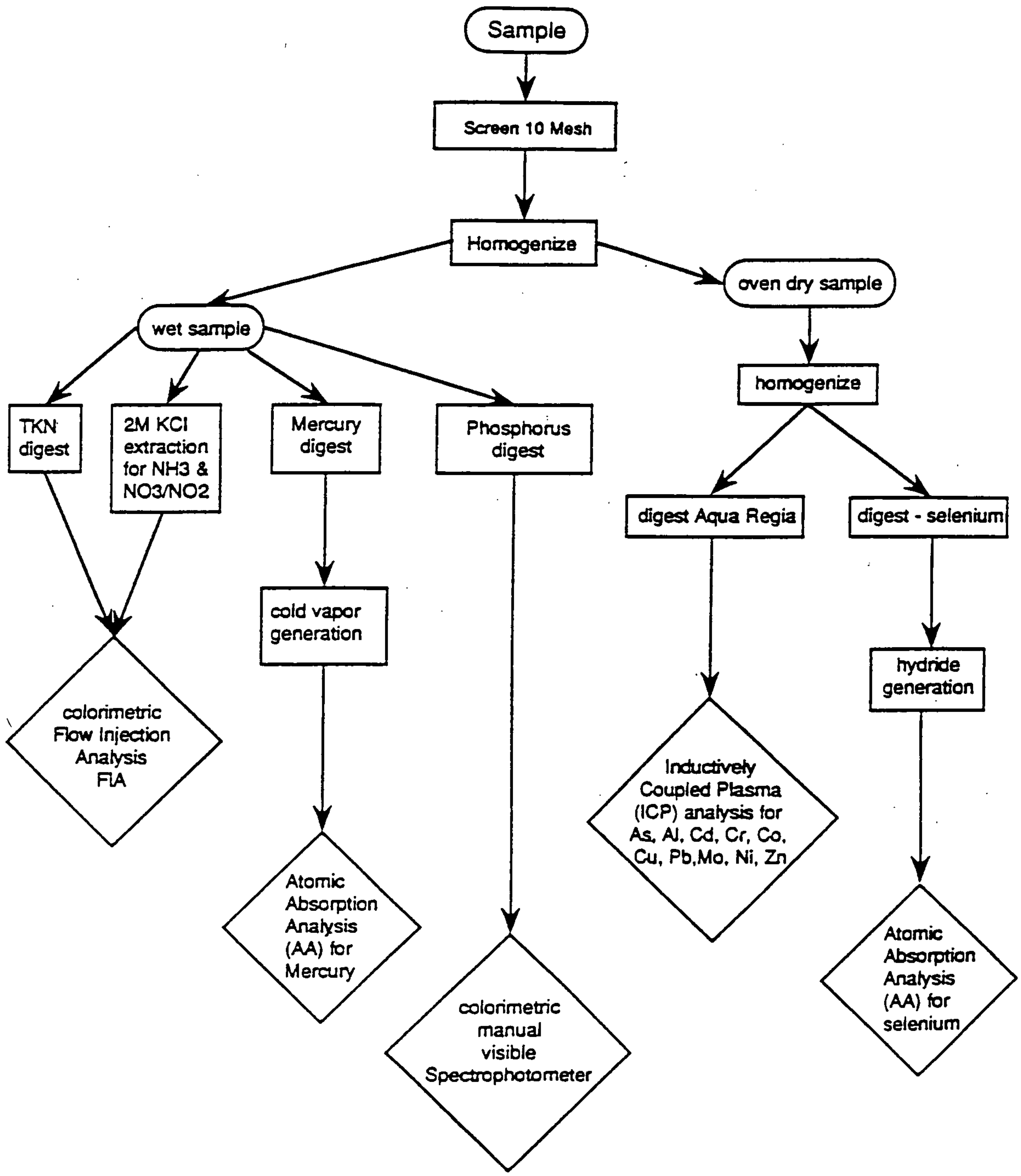
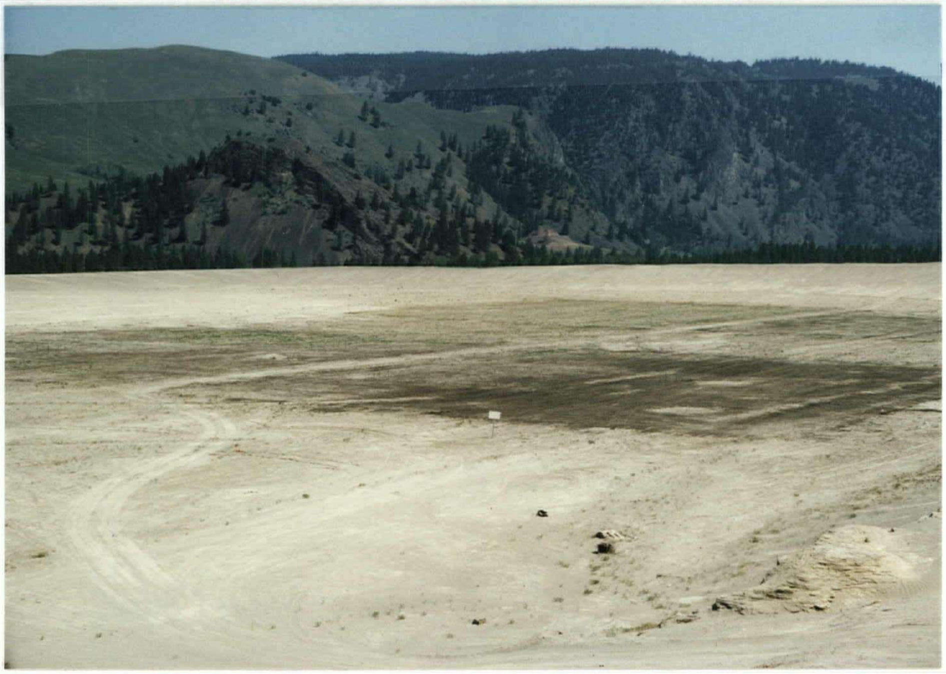
Soil Analysis



APPENDIX P

Photographs

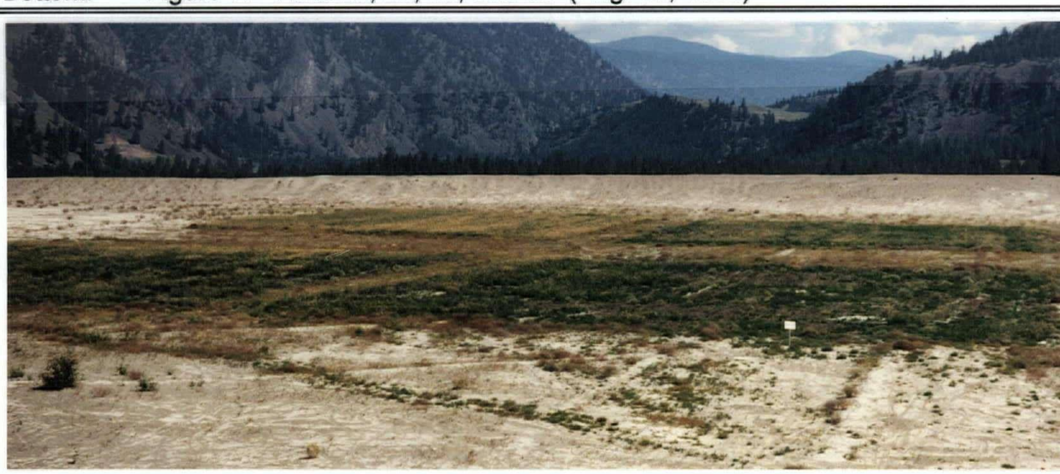
Princeton Tailings Reclamation Project



Top: Figure 5. Plots 2b & 2a (top l. & r.) and Plots 3b & 3a (bottom l. & r.) (May 13, 1993)

Bottom: Figure 6. Plots 2b, 2a, 3b, and 3a (May 23, 1993)

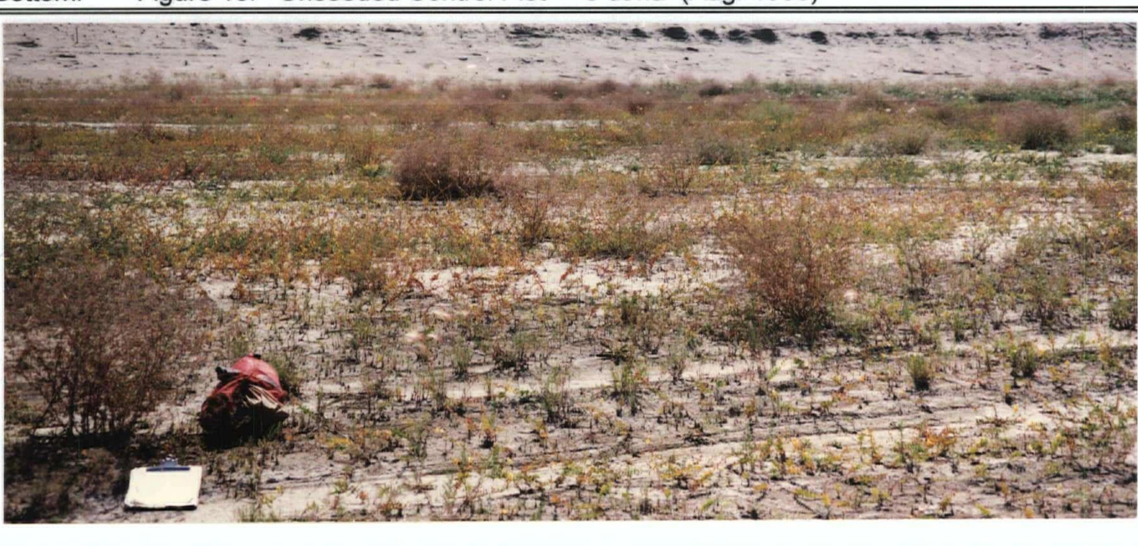
Bottom: Figure 7. Plots 2b, 2a, 3b, and 3a (Aug. 19, 1993)



Top: Figure 8. Plot 2a - 77 dt/ha (Aug. 19, 1993)

Bottom: Figure 9. Plot 3a - 179 dt/ha (Aug. 19, 1993)

Bottom: Figure 10. Unseeded Control Plot - 0 dt/ha (Aug. 1993)



Leaching Experiment

Top l.: Figure 11. Leaching Run 2 - Columns H and I

Top r.: Figure 12. Leaching Run 2 - Column Setup

Bottom: Figure 13. Leaching Run 2 - Columns 1 through 5